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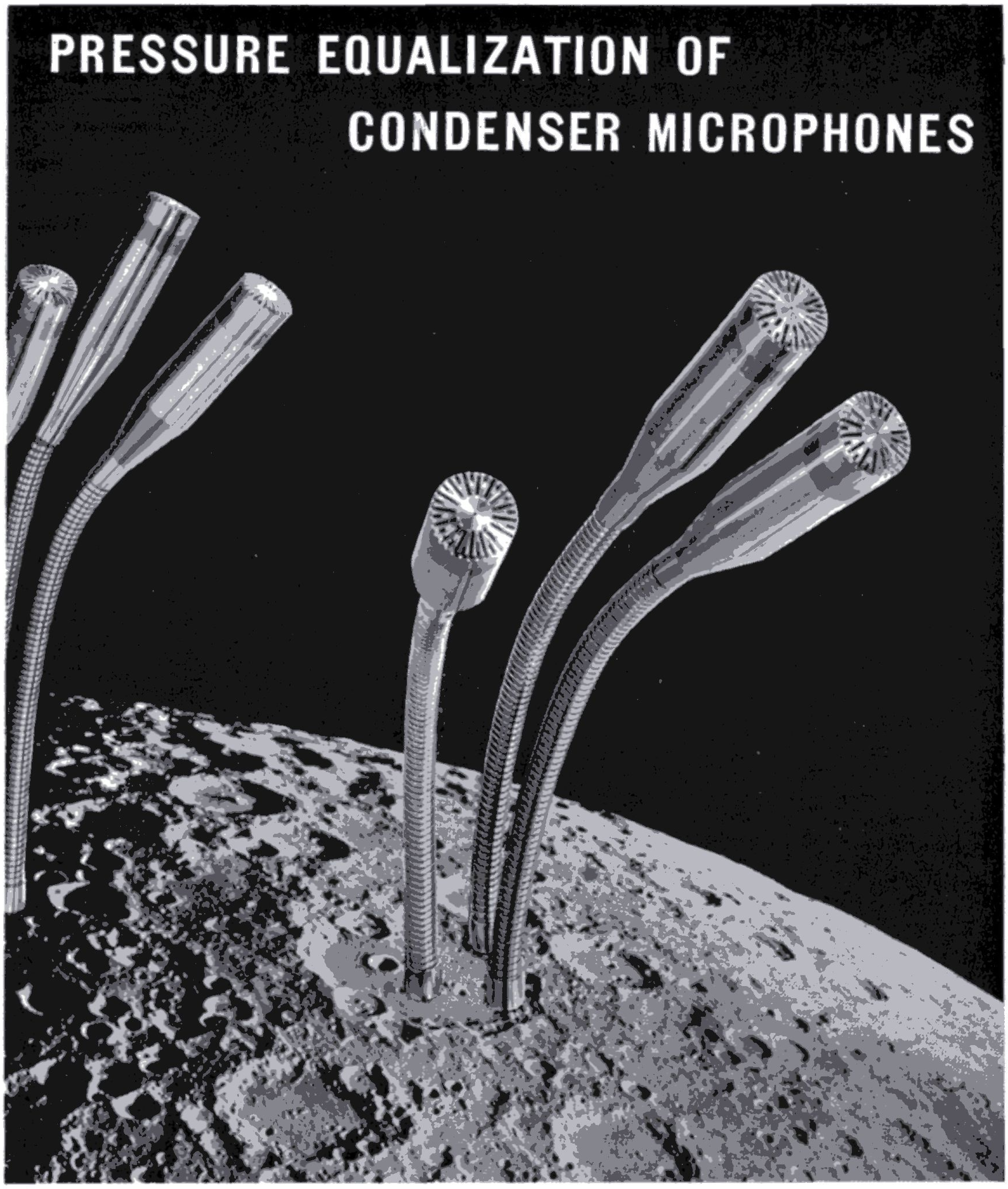

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CONTENT

DET BERLINGSKE BOGTRYKKERI

Pressure Equalization of Condenser Microphones and Performance at Varying Altitudes

by

Gunnar Rasmussen

SUMMARY

The air pressure equalization of most condenser microphones takes place through rather casual openings. This article deals with the importance of keeping the air equalization well under control, and practical measuring set-ups for doing so. Values of the lower limiting frequency for some microphone cartridges are given. The influence of the equalization on the performance under varying environmental conditions of temperature and humidity is discussed, the properties and a few data for the performance at high altitudes are also presented.

ZUSAMMENFASSUNG

Bei den meisten Kondensatormikrophonen findet der Druckausgleich für die hinter der Membran eingeschlossene Luft durch mehr oder weniger zufällige Öffnungen statt. Einesteils beeinflussen die Druckausgleichöffnungen die untere Grenzfrequenz der Mikrofone, andernteils der Kondensatbildung hinter der Membran beim Temperaturwechsel. Dieser Aufsatz behandelt die Wichtigkeit kontrollierbarer Druckausgleichsverhältnisse sowie praktische Messanordnungen zu deren Beobachtung. Die unteren Grenzfrequenzen einiger Mikrofonkapseln werden angegeben. Der Einfluss des Druckausgleichs auf das Verhalten der Kapseln unter verschiedenen Umgebungstemperaturen und -Feuchtigkeiten wird diskutiert und einige Messwerte für grosse Höhen genannt.

RÉSUMÉ

Dans la plupart des microphones l'égalisation de la pression s'opère grâce à des ouvertures qui sont plutôt fortuites. Cet article traite de l'importance qu'il y a à être maître de la manière dont elle se réalise et des dispositifs pratiques de mesure à utiliser pour le contrôle. On donne les valeurs de la fréquence limite inférieure de certaines cartouches. L'influence de l'égalisation sur les performances pour des ambiances de température et d'humidité changeantes est discutée et quelques caractéristiques de performance sous altitudes élevées sont présentées.

A. The Pressure Equalization.

Introduction.

A condenser microphone responds to the difference in pressure between the front and the back of the diaphragm. This difference is obtained either by a difference in phase between the sound pressure at the two sides — pressure gradient microphones — or by keeping the pressure on the one side of the diaphragm constant by mounting it as one of the walls in a closed cavity — pressure sensitive microphones. Nondirectional microphones as normally used for measurements are of the latter type. The cavity terminating the one side of the diaphragm should be so tight that practically no equalization between the pressure inside the cavity and the pressure outside takes place in the frequency range considered.

For sound pressure measurements one is only interested in the measurement of pressure fluctuations above a certain frequency, normally 20 c/s, while influence of changes in ambient pressure and very slow fluctuations such as those obtained from closing doors, wind pressure in and outside wind screens or buildings, or as obtained for climbing or descending vehicles are very disturbing for accurate sound level measurements and should be equalized as quickly as possible. It is also an advantage to have the relative humidity of the air in the cavity equalized with changes in the humidity outside as quickly as possible in order to avoid noisy operation due to condensation of moisture inside the microphone cartridge as shown later in this article.

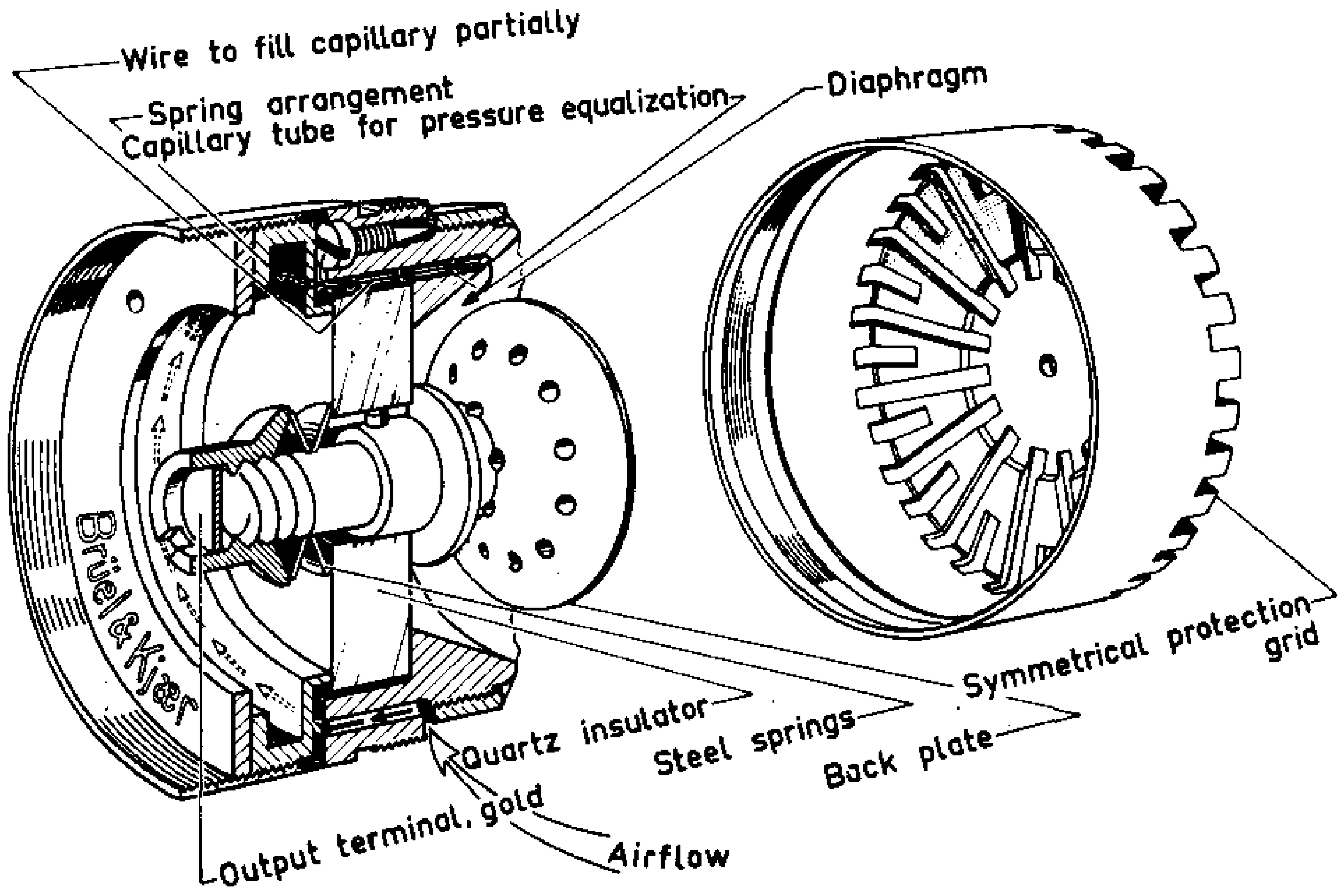


Fig. 1. Sectional view of B & K microphone cartridge Type 4131/32. The path of the air flow is indicated by arrows.

It is thus important to keep the air leakage from the cartridge cavity to the outside well under control. It is an advantage to have the leak terminating to the outside close to the diaphragm independent of the length and tightness of the associated cathode follower. In Fig. 1 and 2 are shown two condenser microphone cartridges with such an equalisation arrangement.

The air flow path is indicated by the arrow. For the type shown in Fig. 1 the air passes through a bore in the housing between the diaphragm suspension ring and the housing, then through a channel between the retaining nut and the housing to the capillary tube in which the flow resistance is adjusted by a wire of a suitable dimension. This arrangement will allow the air to flow down along the sides of the ordinary protecting grid, while it is still possible to exclude the air flow from the front by using a special coupler adapter ring which will pack tight against the edge of the diaphragm suspension ring and only allow air equalization to take place through a small bore in the side wall.

For the small microphone shown in Fig. 2 the air equalization will also take place through a hole in the front, here, however, the flow resistance is determined by a slot in the spacer ring (approx. 20 μ (0.0008″) thick) between the quartz insulator and the cartridge housing. The order of magnitude of the flow resistance in the air equalization system is determined by the lower limiting frequency required and the volume of the cavity behind the diaphragm. This volume again is determined by the amount of air stiffness which could be tolerated at frequencies well below the diaphragm resonance. If the cartridge sensitivity should change no more than e. g. 0.2 db for 10 % change in ambient pressure, the air stiffness should not be more than 20 % of the diaphragm stiffness. That will require a cavity volume so large that the pressure inside the cavity will rise no more than 20 % of the rise in the pressure on the outside when the excess outside pressure depresses the diaphragm into the cavity. The amount of air

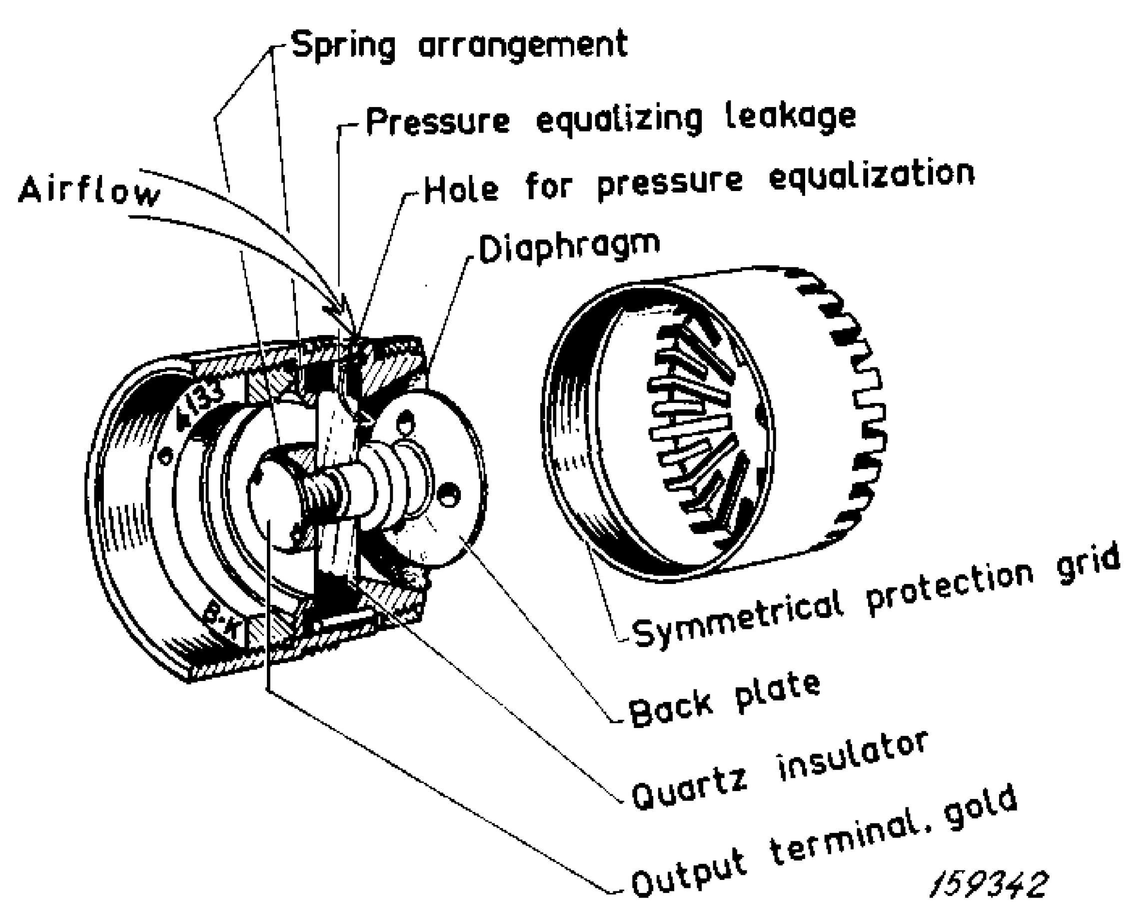


Fig. 2. Sectional view of B & K microphone cartridge Type 4133/34. The Path of the air flow is indicated by arrows.

stiffness present for a certain type of cartridge is easily estimated when the equivalent air volume and the total inside volume is known, e. g. for the Type 4131/32 cartridges the equivalent air volume is 0.1—0.15 cm^3 and the volume of the cavity 0.8 cm^3. The air stiffness will thus be approx. 12—20 % of the diaphragm stiffness. At low frequencies where air equalization takes place, the air stiffness will decrease causing a rise in sensitivity which will show up under certain circumstances as described below.

However, if the distance between the diaphragm center and the opening of the air equalizing system is small compared to the wave length of the sound wave surrounding the microphone, the sensitivity will obviously drop off if equalization of the pressure change takes place.

This peculiarity may lead to errors in measurements.

Measurements.

Ordinary calibration procedures do often not give a true picture of the microphone performance at very low frequencies. Even great errors may be present when a condenser microphone is used for free field measurements. If the microphone cartridge is reciprocity calibrated, pressure calibration is normally always used at low frequencies as the signal to noise ratio is poor below 500 c/s in a free field reciprocity measurement. However, in the pressure calibration are as a rule always used couplers which fit the front side of the microphone tightly, see Fig. 3. In a set-up like this an eventually too large leak would only show up as decrease in sensitivity if the leakage took place through a hole in the diaphragm and as an increase in sensitivity if the leakage took place through the rear of the cartridge cavity. The magnitude of the increase would depend on the ratio of air stiffness to diaphragm stiffness in the microphone. For the microphone types shown in Figs. 1 and 2 the air stiffness at 760 mmHg is about 15 % of the diaphragm stiffness at frequencies below 500 c/s. If thus a reciprocity pressure calibration shows an increase in sensitivity of 0.1 db, due to leakage to the rear of the cartridge, the free field response could be around 1 db down, and for a 1 db increase in the pressure calibration the free field sensitivity would depend only on the phase difference between the pressure on the front and the back of the diaphragm. The same would be true for frequency response calibration with an electrostatic actuator, except that here would always be an increase in sensitivity for any too large leak.

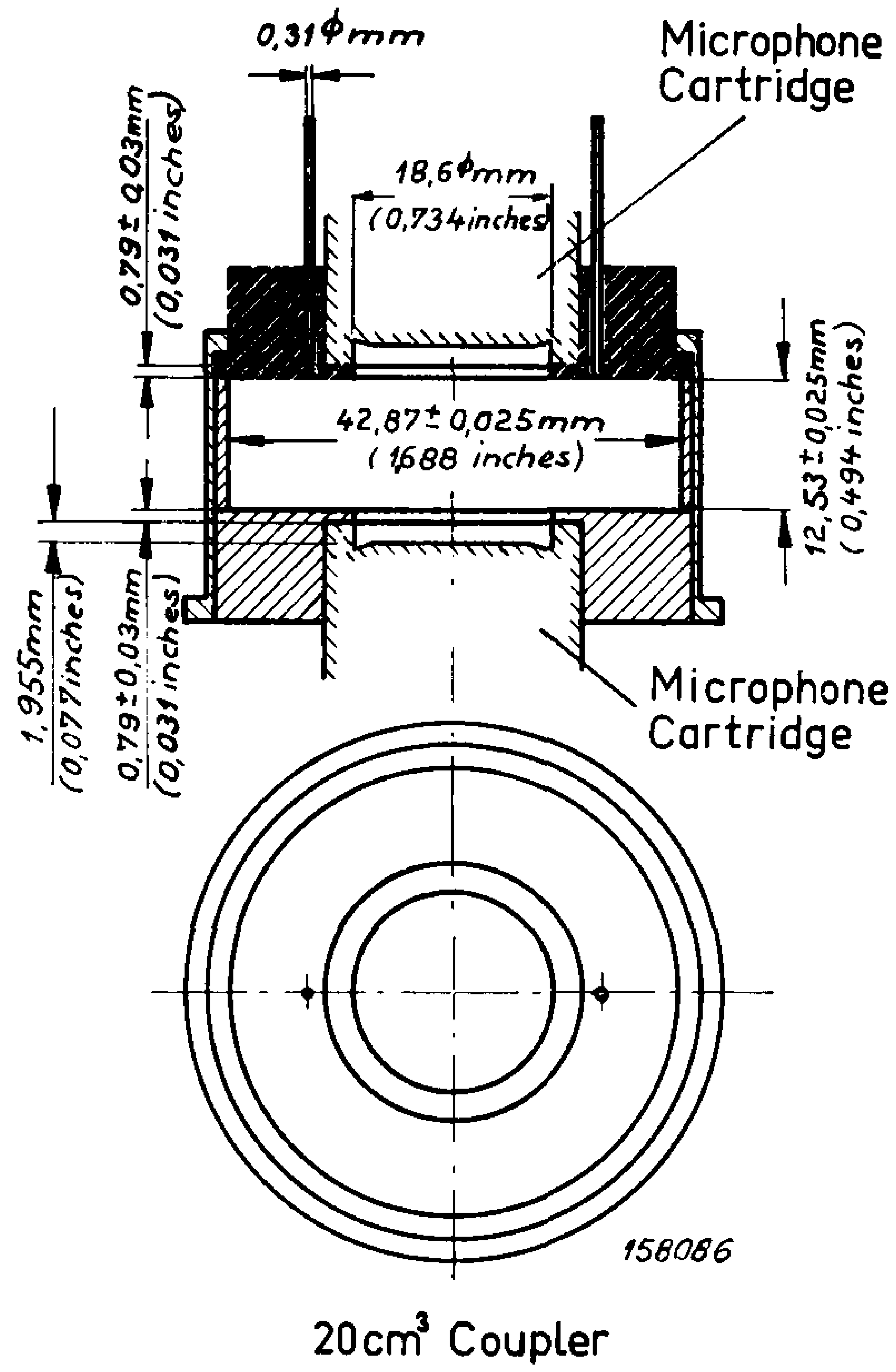
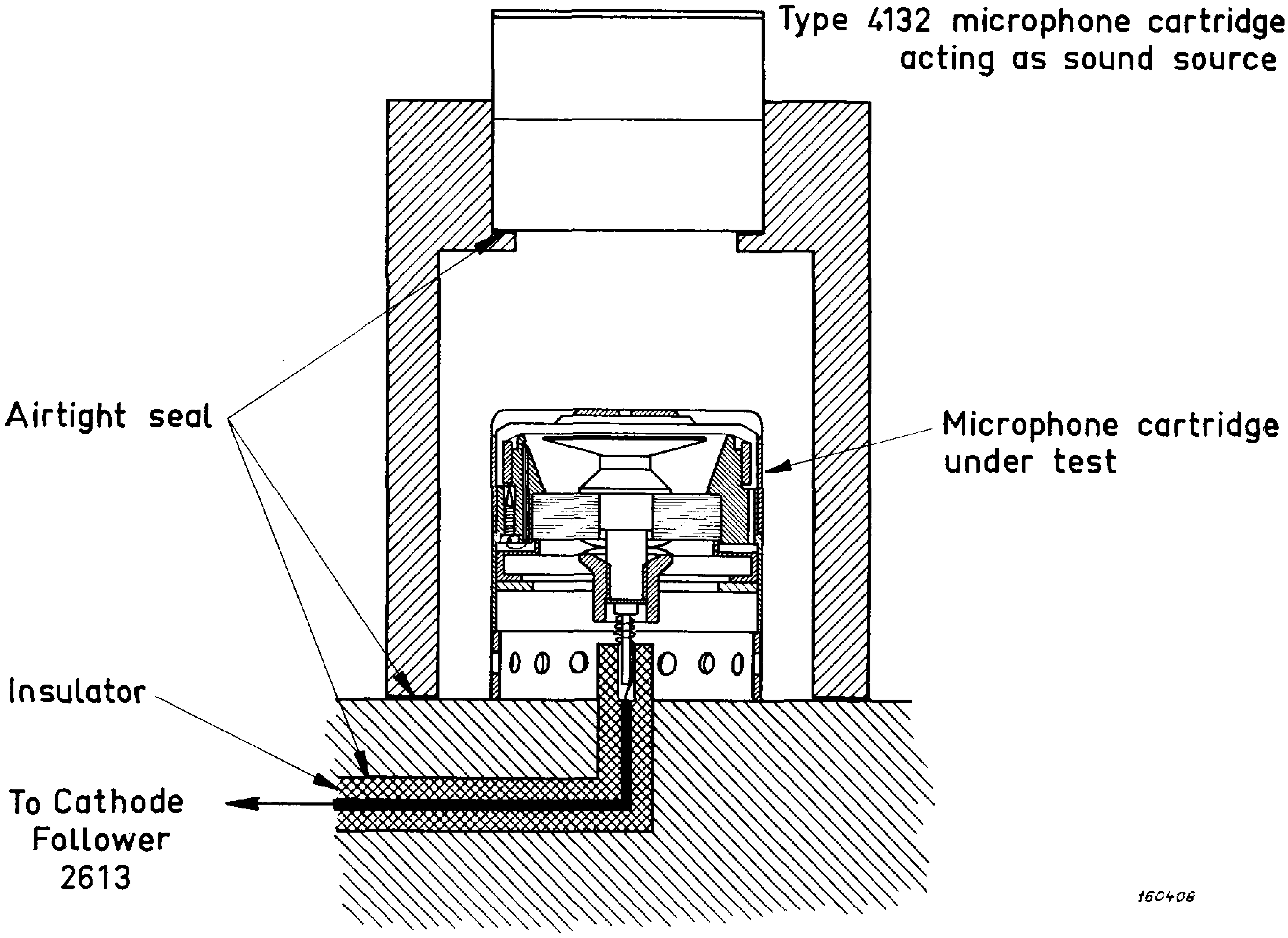


Fig. 3. Typical cavity for reciprocity calibration of Type L. Laboratory Standard Microphones similar to that shown in A.S.A. Standard Z. 24, 4—1949 Fig. 4.



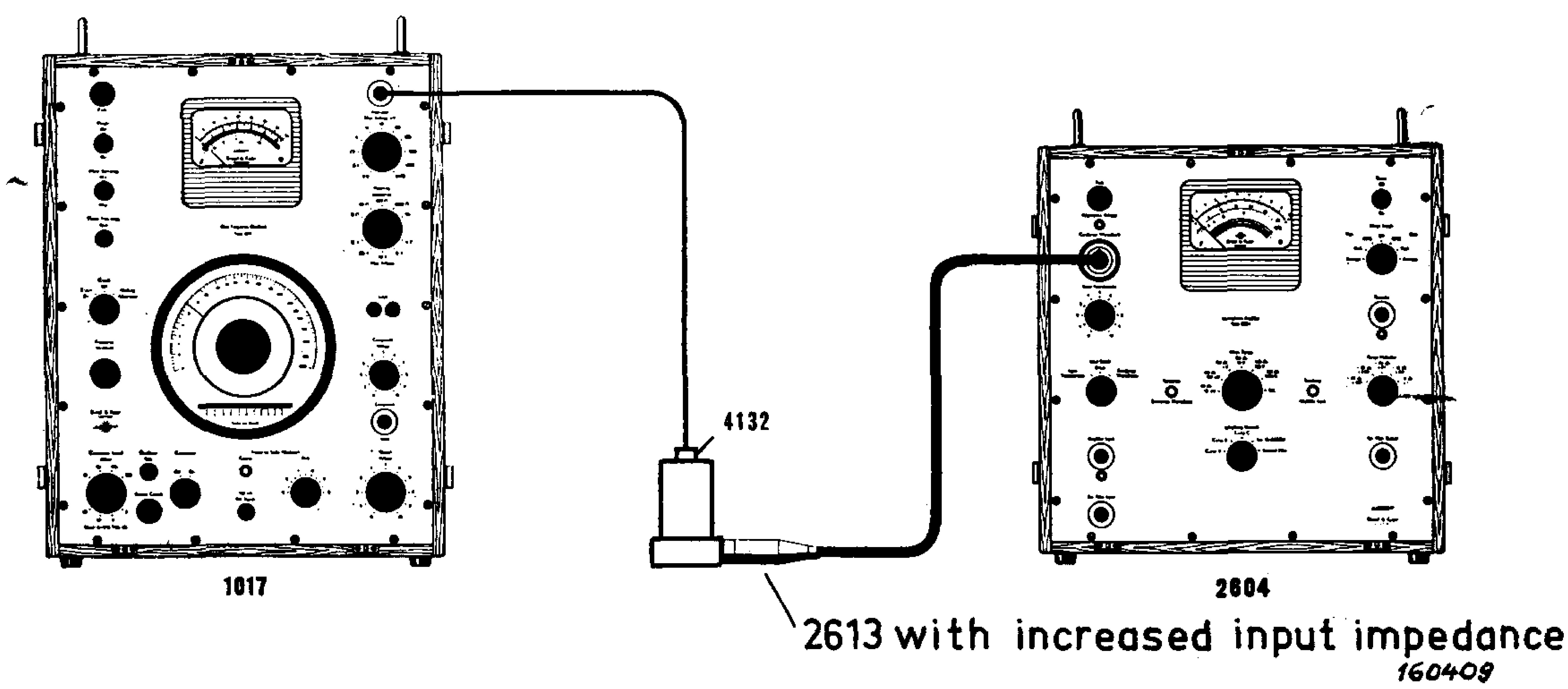


Fig. 4. a) Coupler for the measurement of low frequency response of microphone cartridge. The coupler will allow the pressure fluctuations to surround the cartridges completely.
b) Set-up used in actual production testing.

For the condenser microphones Type 4131/32 shown in Fig. 1 the air equalization is arranged so that it is possible to mount them in couplers with free connection between the coupler cavity and the entrance to the leak leading into the cartridge cavity. This could be done by mounting the cartridges using the B & K coupler adapter ring DD 0011 without the built-in teflon packing washer. This would enable the reciprocity measurement to be carried out down to low frequencies. However, the extra volume introduced will cause a change in pressure in a 3 cm^3 coupler cavity of around 0.4 db. This change will take place at around 400 c/s, and is caused by the hole and the small cavity leading from the front of the cartridge to the airequalizing leak. The arrangement will allow measurements to be carried out directly in the normal B & K reciprocity calibration apparatus Type 4141 and 4142. There is, however, a possibility for air leaking out between the quartz insulator and the retaining nuts or along the thread of the nuts, which is not taken into account by this set-up.

A measuring arrangement which will take also this into account and give a response equivalent to that obtained under free field conditions should allow the sound pressure fluctuations to surround the microphone cartridge completely. This is obtained by the mounting arrangement shown in Fig. 4. A condenser microphone is used as sound source and the cathode follower associated with the receiver cartridge has an increased input impedance which will allow frequency response measurements to be carried out down to 2 c/s. A set-up of this type

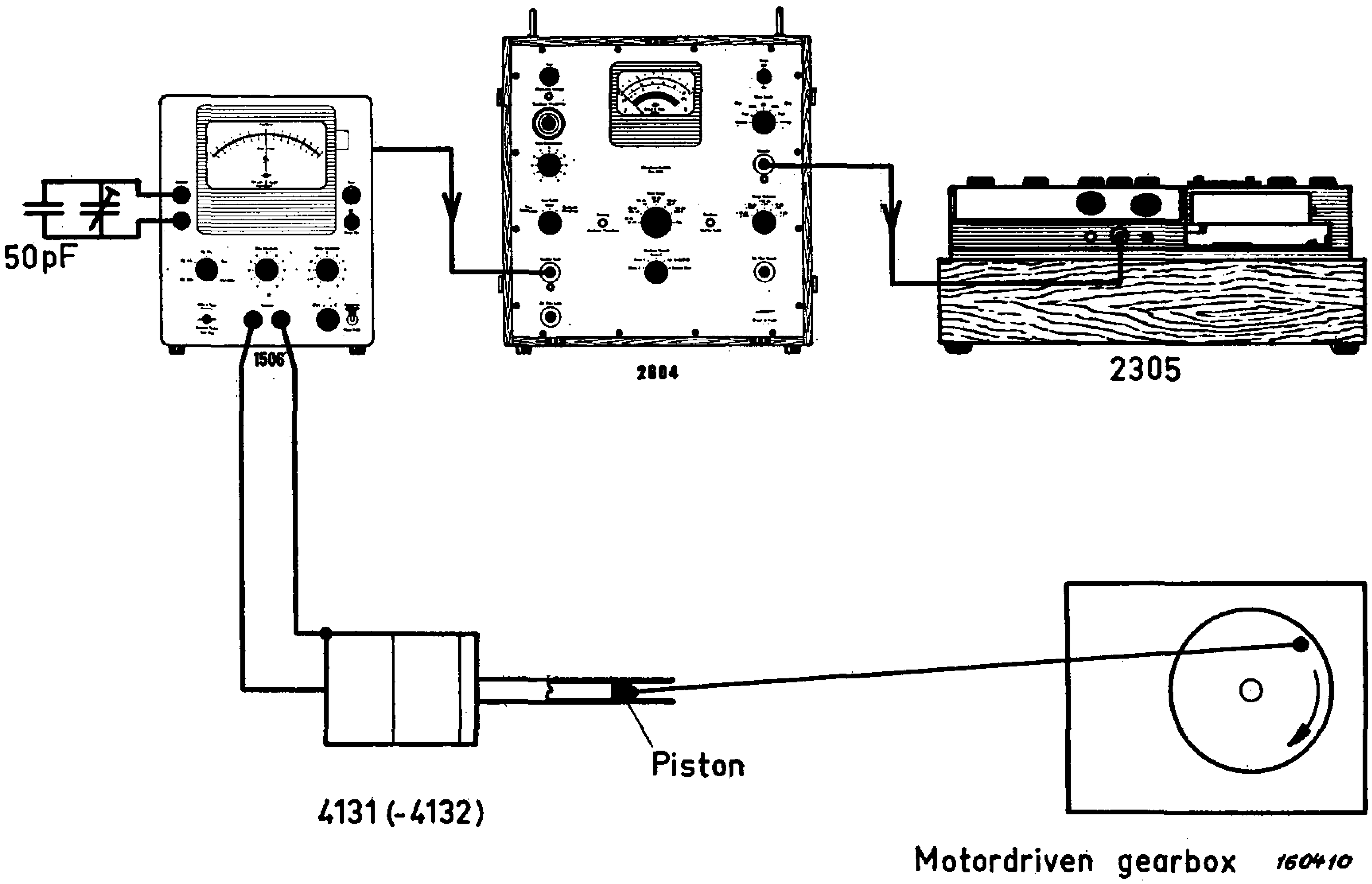


Fig. 5. Arrangement for measurements at very low frequencies.

is now used for production testing of all B & K microphone cartridges Type 4131/32.

For laboratory measurements a pistonphone is used, Fig. 5, which will allow measurements to be carried out down to very low frequencies. In this set-up the cathode follower was replaced by a deviation test bridge B & K Type 1506, and the capacity fluctuations rather than the output voltage was measured. The capacity fluctuations were recorded on a B & K Level Recorder Type 2305, a typical recording for the frequencies 10—3—1 c/s is seen in Fig. 6. The arrangement may be used for measurements down to 0.001 c/s. In Fig. 7 are shown four curves giving the open circuit voltage versus frequency for the cartridges Type 4131/32 for different air equalization arrangements. The acoustical resistance of the equalization is determined by the flow resistance of an 0.31 mm inside diameter capillary tube 7 mm long, more or less filled with wire of different diameters. If the frequency response should be linear down to 20 c/s, a wire of 0.25 mm should be preferred. In actual production of the microphone cartridges wire dimensions of 0.25 — 0.26 — 0.27 mm are used for adjustment to keep the 3 db lower limiting frequency on 3 c/s ± 1 c/s. As may be seen from Fig. 7 this choice will ensure less than 0.3 db error at 20 c/s, and yet it will allow a rather low air equalization time.

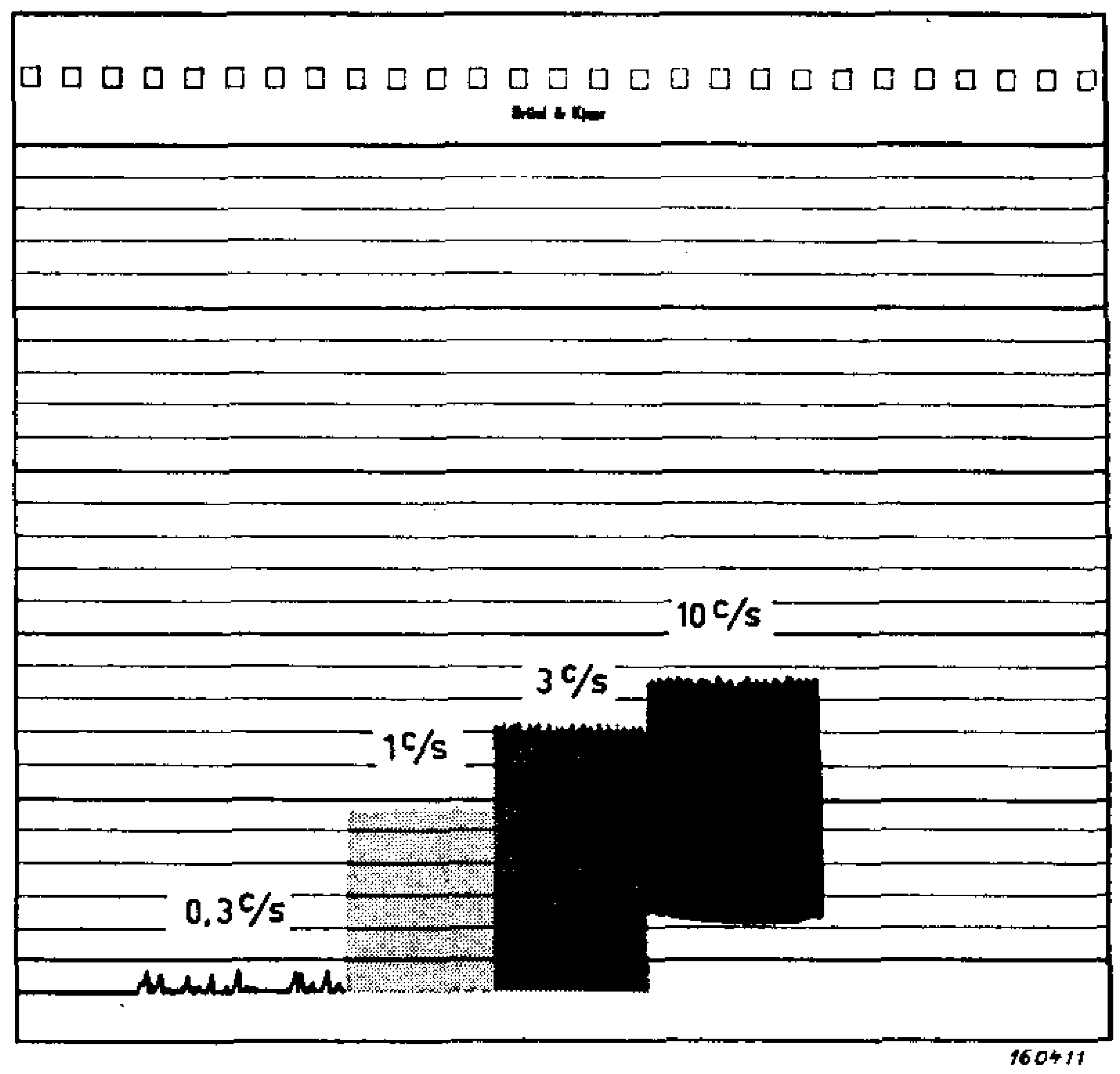


Fig. 6. Typical recording as obtained from the set-up shown in Fig. 5.

For the smaller cartridges (Type 4133/34) the frequency response for the normal air equalization and for extra small air equalization is shown in Fig. 8. For this cartridge a 3 db limit at 1 c/s has been chosen as a normal production value.

It is rather difficult to obtain comparable data for other microphone constructions. Many microphones are depending on the associated amplifier and thus, rather difficult to measure and specify. A few commonly used constructions have

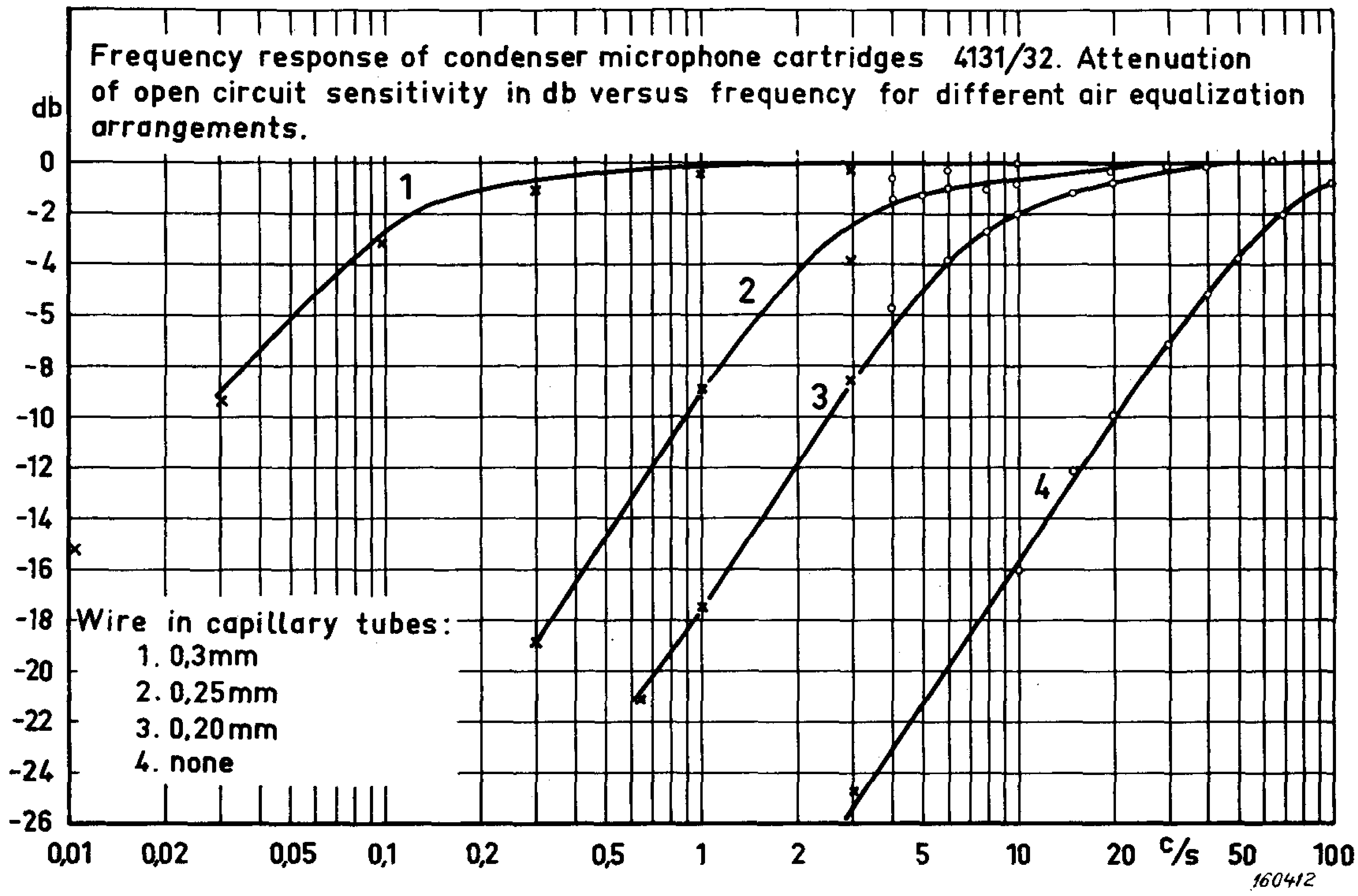


Fig. 7. Open circuit low frequency response for the Microphone Cartridges Type 4131 and 4132.
o points obtained by the set-up shown in Fig. 4.
x point obtained by the set-up shown in Fig. 5.

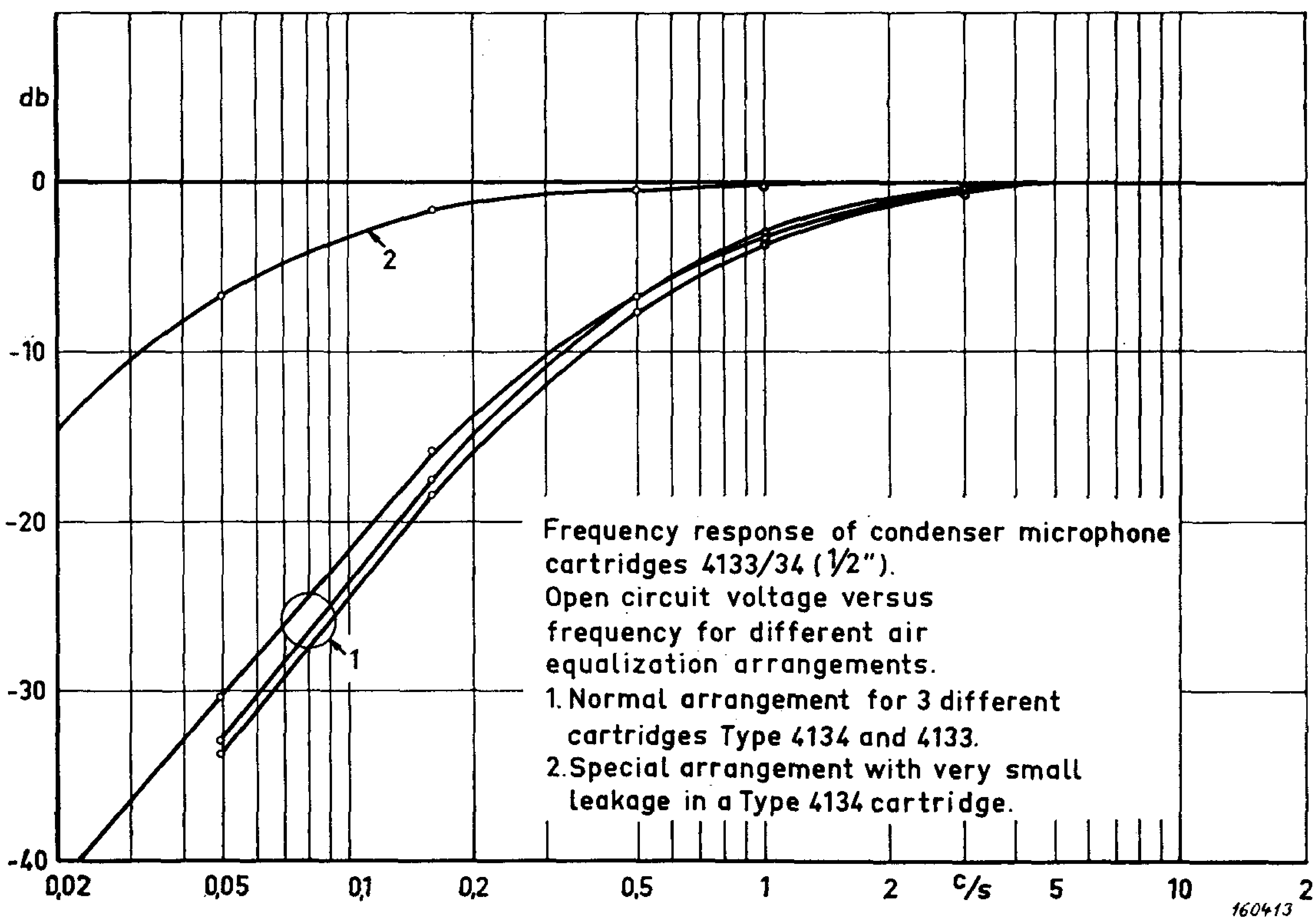


Fig. 8. Open circuit low frequency response for the Cartridges Type 4133 and 4134.

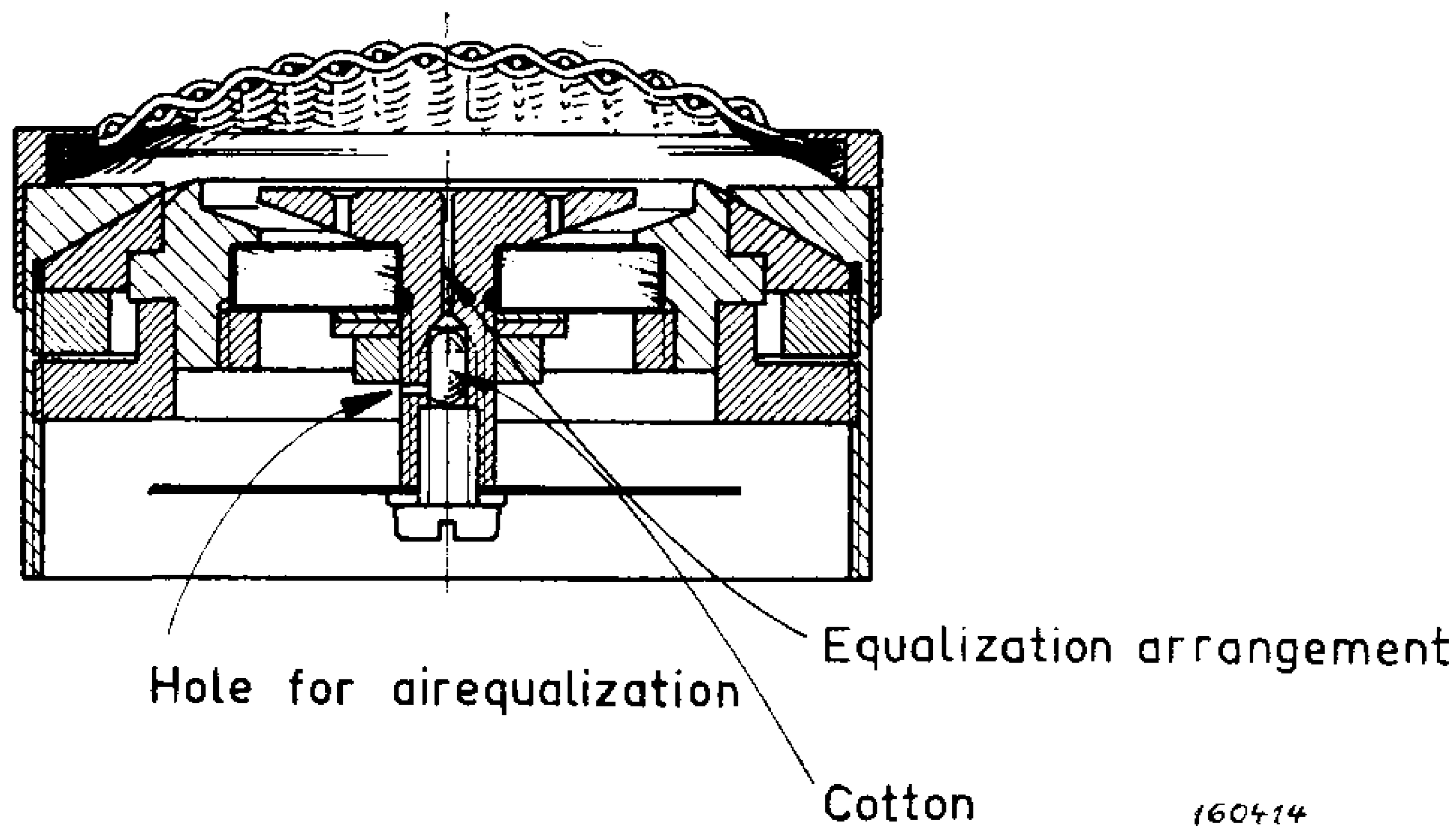


Fig. 9. B & K Microphone Cartridge MK 0001, used in the old B & K Microphones Type 4111.

been evaluated. The cartridge used in the old B & K Condenser Microphones Type 4111 is shown in Fig. 9. Here the air flow is led from the cavity through a hole in the center of the back plate to a small space, filled with cotton to obtain the necessary flow resistance, and out through a hole in the side of the output terminal. The resistance and thus the lower limiting frequency of this arrange-

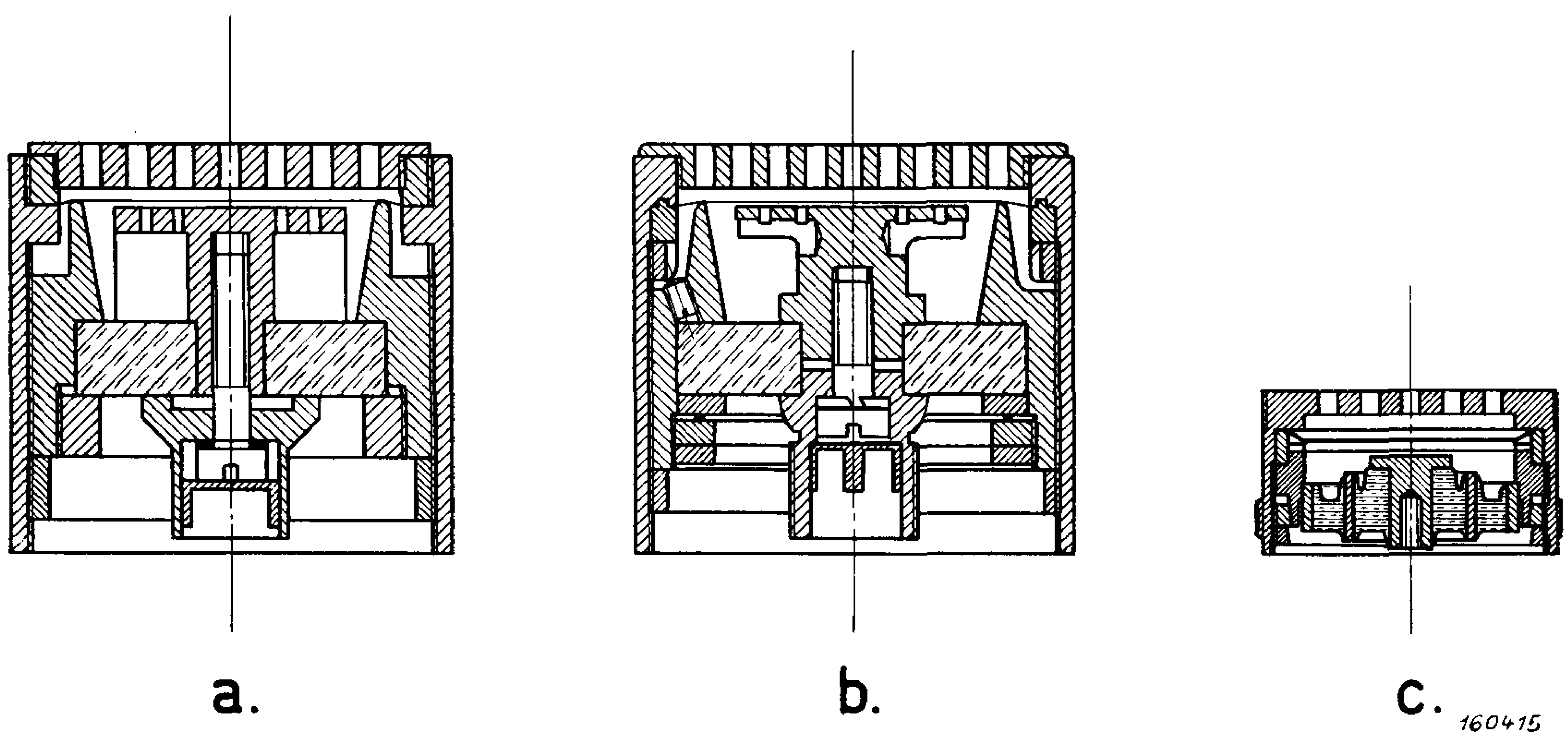


Fig. 10. Sectional views of commonly used microphone cartridges.

ment may vary over a rather wide range. Fig. 10a shows a sketch of a cartridge for which the lower limiting frequency has been measured to 7 c/s for one unit and below 0.02 c/s for another unit. Only one unit of the design shown in Fig. 10b has been investigated and the lower limiting frequency was here extremely low. The air equalization for both types of cartridges will take place through small openings between the housing and the insulator out to the rear of the cartridge. The cartridge sketched in Fig. 10c employs a glass diaphragm clamped to the front of the housing by a spring. The air equalization may thus be expected to take place to the front. The 3 db limit for the one unit available was measured to lie below 0.05 c/s.

Sensitivity to Moisture.

When a microphone is moved from a warm to a cold place, moisture condensation may take place. In this case it is important that the pressure equalization arrangement connects the inside of the microphone directly to the outside atmosphere (microphone cartridges Type 4131—4132—4133 and 4134) instead of connecting it to the atmosphere via the volume of the associated amplifier. The latter arrangement is used both on other microphones and on the older B & K Microphone Type 4111.

A microphone cartridge will always contain a certain amount of water vapour, depending on temperature and relative humidity. If the cartridge is cooled down, the relative humidity will increase very rapidly and soon reach 100 % where condensation will start. This condition may result in a noisy microphone cartridge. So it is important that the condensed water escapes from the cartridge through the pressure equalization tube as soon as possible, and to know at what rate a certain amount of water is released. A calculation of the diffusion process through the pressure equalization tube has been tried but seems very difficult to carry out to any reasonable degree of accuracy. The results obtained from simple experiments with a 4131 microphone, however, seem to be much more reliable.

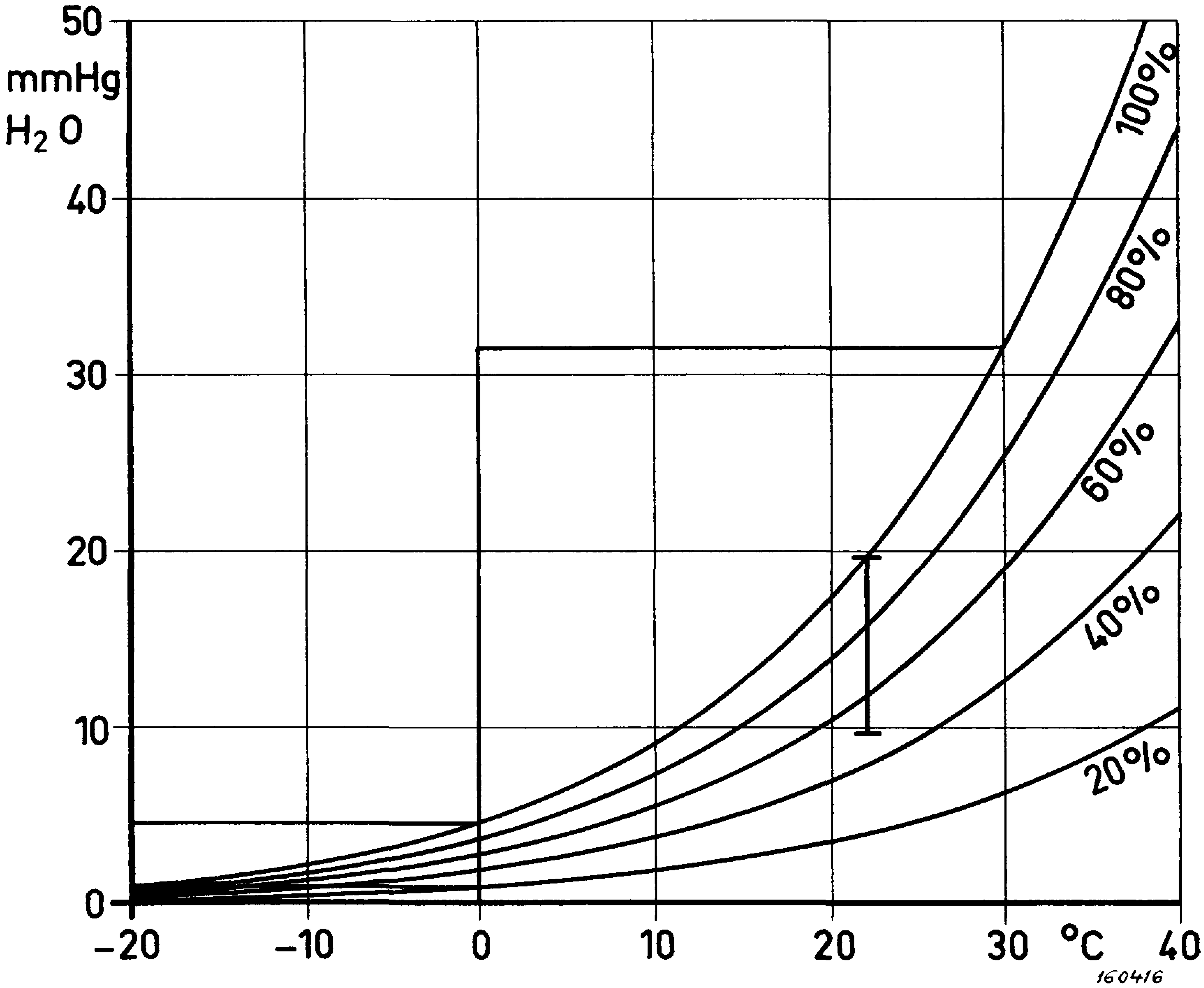


Fig. 11. Curves showing the H_2O partial pressures versus temperature and relative humidity.

A droplet of water was injected in a microphone and the cartridge was weighed on a very accurate balance. The cartridge was then stored at an ambient temperature of 22° C and relative humidity of 49 % for some days, and the decrease in weight determined twice a day.

The amount of H_2O diffusion is proportional to the difference in the H_2O partial pressures outside and inside the cartridge. It can be assumed that the relative humidity inside the cartridge was 100 % and by looking into the humidity diagram shown in Fig. 11 it can be seen that the difference in H_2O partial pressures between the inside and the outside atmosphere was 10 mmHg.

The experiment showed that the amount of water released per minute was 2.3 μg, which corresponds to a diffusion rate of *0.23 μg/min for a difference in partial pressures of 1 mmHg,* (a diffusion 1.3×10^{14} molecules H_2O per second).

Fig. 12 shows a sketch of a microphone which is assumed to have been stored for some time at 30° C and 100 % humidity where the partial H_2O pressure is 31.5 mmHg. The microphone is then placed in an environment with a temperature of minus 20° C, again with a relative humidity of 100 %. The microphone cartridge itself will be cooled off rather rapidly, and with the cathode follower in operation it will end up with a temperature of 0° C, whereas the warm cathode follower will only drop down to 5° C. When stable temperature conditions are reached simple calculations show that 22.8 μg H_2O in liquid form will be present in the 0.8 cm^3 internal volume of the cartridge* (Type 4131 and 4132). The condensa-

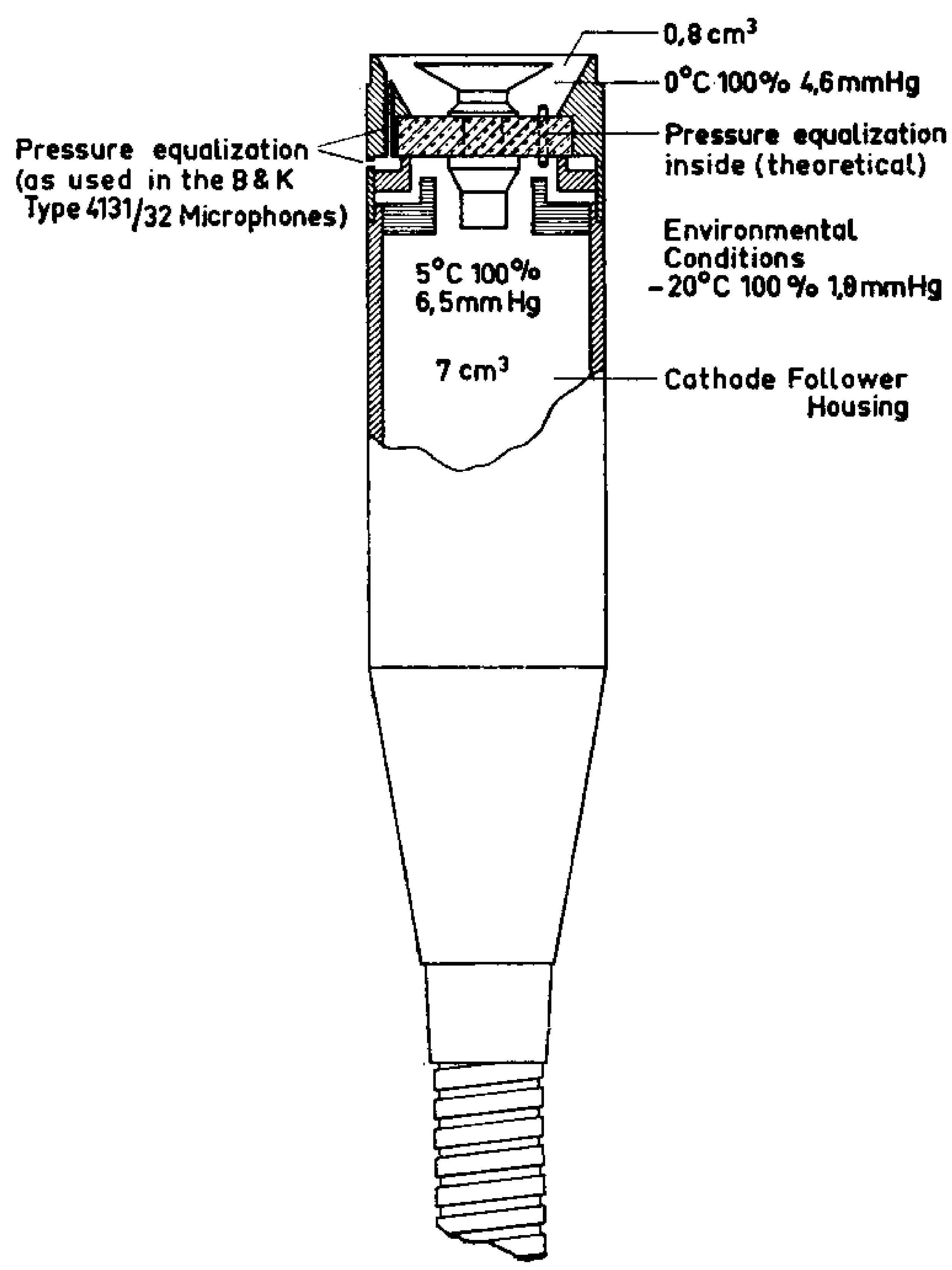


Fig. 12. Sketch of a condenser microphone cartridge and cathode follower showing the pressure equalization at used on the B & K microphones fully drawn as well as an example of equalization through the cathode follower housing (dotted lines).

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* See for instance "Kohlrausch. Praktische Physik", Bind II, page 520, table 28.

tion of moisture will take place on the parts of the microphone which are cooled down first, primarily on the free parts of the diaphragm between the back plate and the rim. Fortunately no condensation will in the beginning take place between the diaphragm and the back electrode, as the back electrode is the last part of the microphone to be cooled down, and the small distance between the electrode and the diaphragm will keep the diaphragm at a relative high temperature, thus preventing condensation from taking place in the most critical areas. This phenomenon is easily demonstrated by taking a relative cold cartridge and breathe on it. On the outside of the diaphragm is seen a picture of the back electrode owing to the heat exchange between the electrode and the thin diaphragm. Fig. 13 shows a picture of this effect.

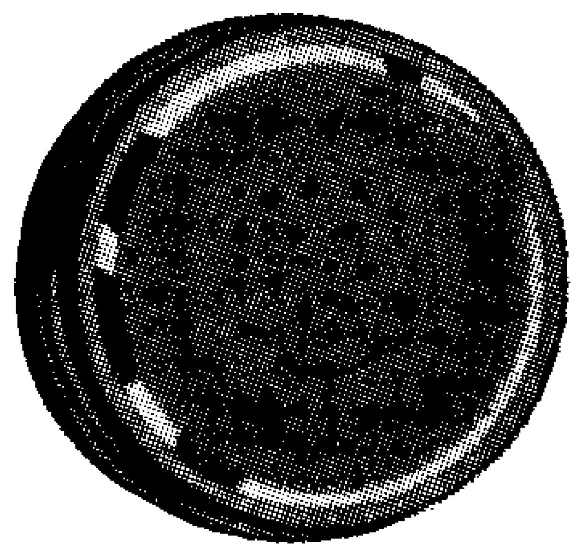


Fig. 13. Snapshot of moisture condensation on a cold cartridge showing the effect of the heat exchange from the back plate to the diaphragm.

Turning back to Fig. 12, where the cool microphone contains 22.8 μg H_2O, the partial H_2O pressure will be 4.6 mmHg, and as the outside partial pressure at —20° C is 1.0 mmHg the difference in H_2O pressures is 3.6 mmHg, which will release 0.83 μg/min. Consequently it will take about 20 minutes before the 22.8 μg condens water in the microphone has disappeared. In most cases, however, no trouble will arise from cooling off the microphone relatively quick because the condens water will be present in non-critical areas, leaving the microphone ready for immediate use.

On the other hand, when a cool microphone is brought into a hot atmosphere some of the H_2O in the hot atmosphere will diffuse into the cartridge cavity and cause moisture condensation of the coldest places, that is just between the electrode and the diaphragm. A risk of noise and cracking does then exist. Experience has shown, however, that under very severe conditions noise has been observed for about 7 minutes for a 4131 microphone cartridge.

Something different will happen if the pressure equalization is not taking place directly to the free but — as indicated on Fig. 12 by dotted lines — to the inside of the cathode follower, the air volume of which is about 7 cm^3. If we assume that the cathode follower is equalized at around the same rate as the cartridge, a part of the H_2O content in the cathode follower will diffuse into the cartridge causing moisture condensation there, the cartridge being the coolest part of the complete assembly. As the resistance through the cathode follower will make it more difficult for the water from the cartridge to diffuse out, the "out of operation" time may be very long. If the pressure equalization leakage is very small, e.g. corresponding to a lower limiting frequency of 0.1 c/s instead of as usual 3 c/s in 4131 the problem of removing condens water will be greatly increased. We are convinced that many difficulties with condenser microphone cartridges of different types can be traced back to the fact that the microphones have very poor equalization characteristics, and trouble will, consequently, arise not only from change in ambient static pressure, but also from moisture condensation.

Rate of Climb.

The pressure equalization is very important when the microphone is used under conditions where rapid variations in the ambient static pressure occur, as f.ex. when sound measurements are made in aircraft during flight.

To determine the maximum allowable rate of change in ambient pressure (rate of climb), when the maximum allowed change in microphones sensitivity is given, it is necessary to calculate the air flow through the equalization arrangement. When the internal volume of the microphone cartridge is known, and if the equalization arrangement consisted of an ideal capillary tube or slot the calculations could be readily performed by means of known formulae.*

In practice, however, the pressure equalization arrangement very seldom consists of an ideal capillary tube, and it is therefore almost impossible to perform this type of calculations with any reasonable degree of accuracy. A much more convenient method is to consider the electrical analogue of the pressure equalization and from the lower 3 db frequency limit determine the flow resistance of the equalization arrangement.

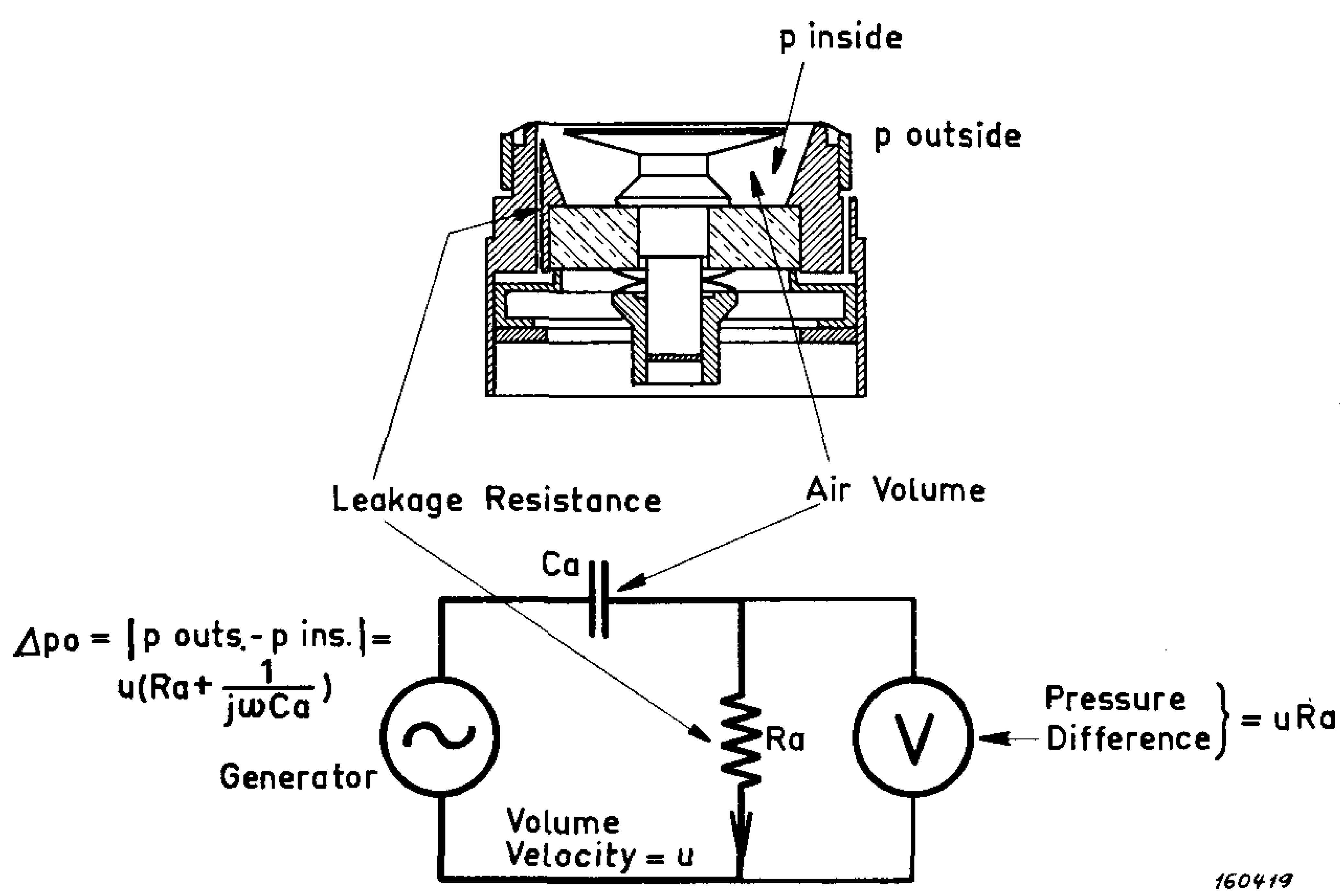


Fig. 14. Equivalent circuit of the pressure equalization.

* Lord Rayleigh: Theory of Sound, Vol. II, p. 327.

At low frequencies the internal volume of the cartridge can be considered equivalent to an acoustic capacitor, C_a, and the flow resistance of the pressure equalization arrangement as an acoustic resistor, R_a. This is illustrated in Fig. 14. The generator shown equals the sound pressure on the microphone diaphragm. The pressure difference between the outside and inside of the microphone cartridge will consequently be represented by the voltage drop, V_a, across the resistor R_a.

At higher frequencies the impedance of the capacitor is negligible compared to R_a, and the pressure difference will be equal to the sound pressure on the diaphragm. When the frequency of the generator is decreased, however, the pressure difference across R_a, that is the voltage in the equivalent circuit, also decreases. At zero frequency the voltage is zero and no difference in pressure exists.

When the pressure difference has dropped off 3 db from its maximum value the acoustic impedance of the capacitor equals the resistance R_a:

$$R_a = \frac{1}{2\pi \cdot f_u \cdot C_a} = \frac{\rho\ c^2}{2 \cdot \pi \cdot f_u \cdot V} \quad \text{(Rayl)}$$

where

$$C_a = \frac{V}{\rho\ c^2}$$

f_u = lower limiting frequency (3 db point)
(for the 4131/32 cartridges normally 3 c/s, and for the 4133/34 cartridges normally 1 c/s).

ρ = density of air in g/m³ = 0.0012 (at ground level).

c = velocity of sound in air in cm/sec = $3.44 \cdot 10^4$ (at ground level).

V = inside volume of cartridge in cm³
(for the 4131/32 cartridges 0.8 cm³, and for the 4133/34 cartridges 0.14 cm³).

The volume velocity, u, of the air flow through the equalization arrangement will be

$$u = \frac{p}{R_a}$$

where p is the pressure difference across the equalization leak.

The pressure, p, which will cause a change of β per cent in the microphone sensitivity, may be calculated when the microphone sensitivity, S, in mV/μbar for a certain polarization voltage, E_o, is known.

Since a change, Δx, in the spacing, x, between the diaphragm and the back electrode will have the same effect upon the sensitivity as a change ΔE_o in the polarization voltage, the following relationship holds:

$$\frac{\Delta x}{x} = \frac{\Delta E_o}{E_o} = \frac{\beta}{100} \quad \text{for } \Delta E_o << E_o$$

that is $$\Delta E_o = E_o \cdot \frac{\beta}{100} \text{ and } \Delta E_o = S \cdot p$$

that is $$p = \frac{E_o \cdot \beta}{S \cdot 100}$$

The volume velocity will then be

$$u = \frac{p}{R_a} = \frac{E_o \cdot \beta}{S \cdot 100 \cdot R_a}$$

When the change in pressure with altitude ($K \mu bar/m$) is known, it is possible by means of the law of Gases to derive the following expression for the rate of climb:

$$\frac{\Delta h}{\Delta t} = \frac{u \cdot P}{V \cdot K}$$

assuming that the temperature during climb is constant.
P is the ambient atmospheric pressure.
Introducing the foregoing expressions for the acoustical resistance and the volume velocity, the expression for the climb rate can be written:

$$\frac{\Delta h}{\Delta t} = \frac{P \cdot E_o}{V \cdot K \cdot R_a \cdot S} \cdot \frac{\beta}{100} = \frac{2 \cdot \pi \cdot f_u \cdot E_o}{S} \cdot \frac{P}{c^2 K} \cdot \frac{\beta}{100} \text{ m/sec}$$

The rate of change in static pressure, K, the velocity of sound, c, and the density of the air, ρ, vary with altitude. Some typical values at different altitudes together with the correction factor, which should be used when the climb rate at ground level is known, are given in the table below:

Altitude in m	Pressure in 10^3 μbar P	Density in gr. cm^{-3} ρ	Speed of Sound in m sec. C	Rate of change in μbar m^{-1} K	Increase in ascent rate with altitude factor
0	1013	0.00122	340	120	1
5000	540	0.00074	321	72	1.5
10000	264	0.00041	300	40	2.7
15000	120	0.00019	295	19	5.7
20000	55	0.00009	295	9	12

For the B & K Microphone Cartridges Type 4131/32 the normal 3 db lower limiting frequency f_u for the open circuit voltage is 3 c/s. The average sensitivity is 5 mV/μbar and the polarizing voltage 200 V. For an allowable change in sensitivity of 1 db the climb rate at ground level will be

$$\frac{\Delta h}{\Delta t} = \frac{1013 \cdot 10^3 \cdot 200 \cdot 0{,}12 \cdot 2 \cdot 3}{120 \cdot 0{,}0012 \cdot 3{,}4^2 \cdot 10^8 \cdot 5 \cdot 10^3} = 525 \text{ m/sec.}$$

If the wire in the capillary tube (see Fig. 1) is removed the 3 db lower limiting frequency is approx. 55 c/s, and the rate of climb will be 9600 m/sec (31600 feet/sec).
For the cartridges Type 4133/34 a 3 db lower limiting frequency f_u of 1 c/s has been chosen. At ground level the climb rate for 1 db change in sensitivity will then be approx. 740 m/sec. In Fig. 15 the rate of climb is shown both for the microphones 4131/32 and for the 4133/34 versus altitude. In Fig. 16 curves are given for the variation in climb rate as a function of the 3 db lower limiting frequency.
As may be seen from the above expression the climb rate is determined by two characteristics of the cartridge only, namely the air equalization in terms of lower limiting frequency and the diaphragm deflection in terms of sensitivity in

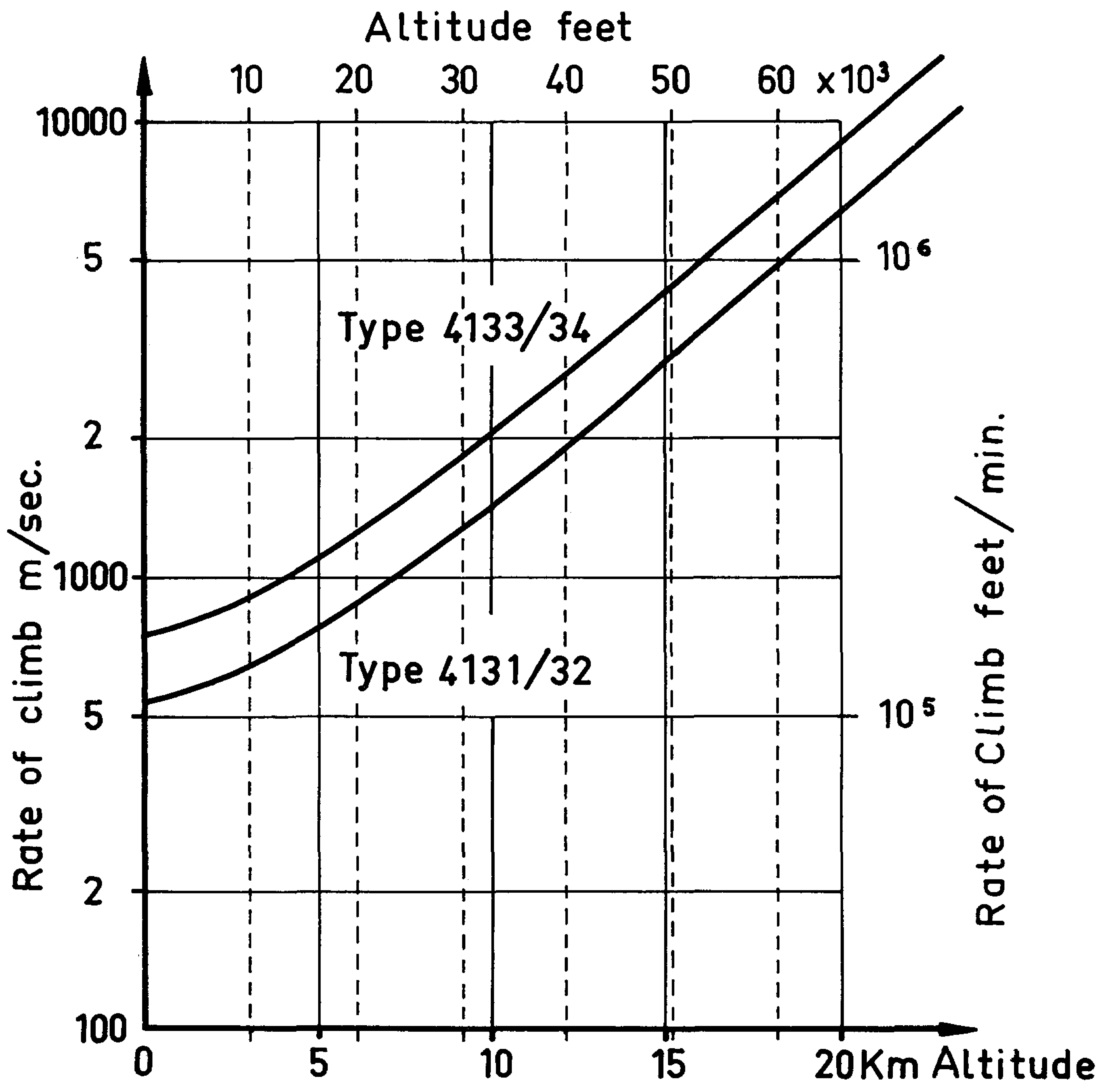


Fig. 15. Variation in rate of climb versus altitude for the microphone cartridges Type 4131/32 and 4133/34.

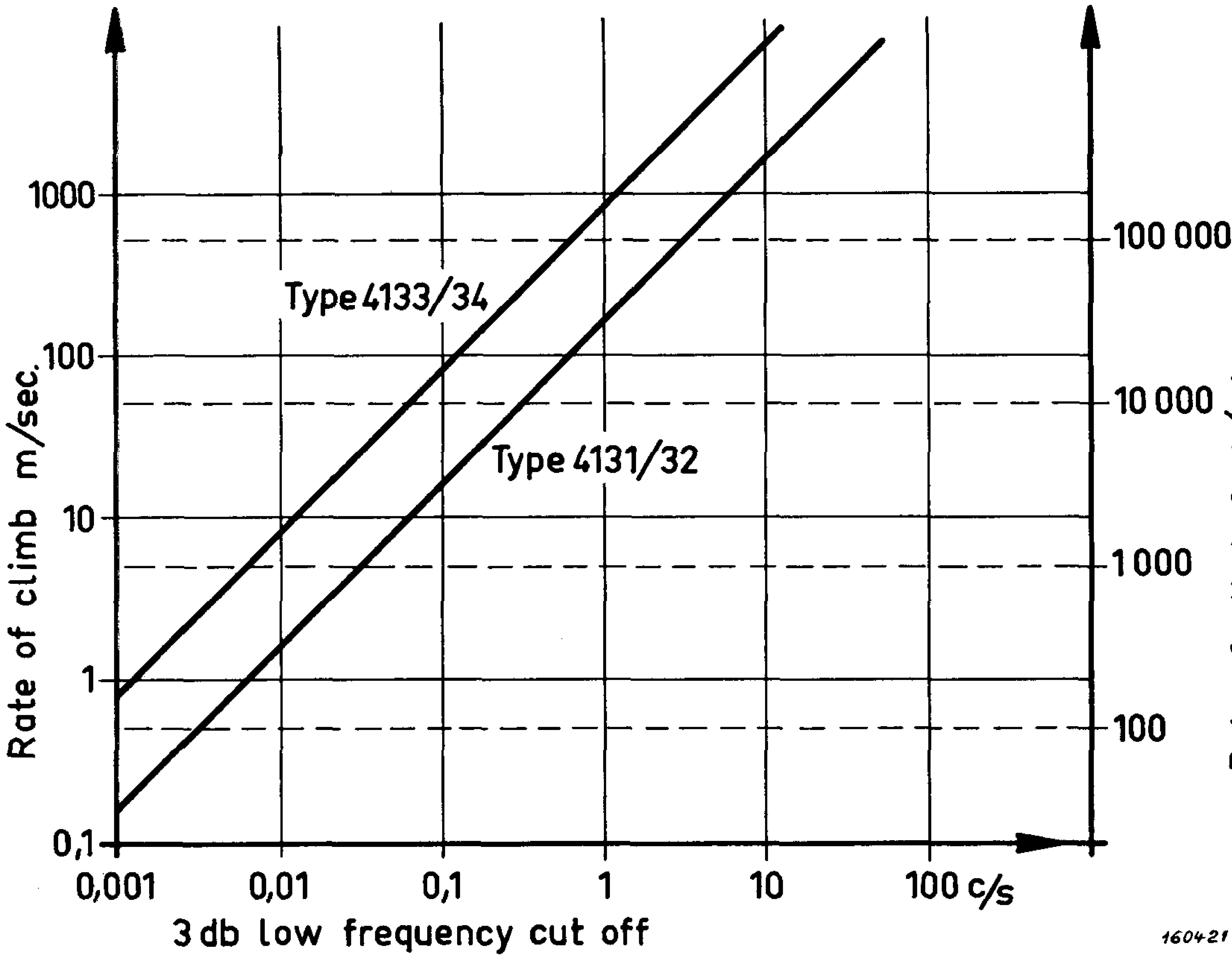


Fig. 16. Variation in rate of climb for change in lower limiting frequency for microphone cartridge Type 4131/32 and 4133/34.

mV/μbar for a given polarization voltage. A microphone with a low sensitivity will allow a higher climb rate than one with a high sensitivity for the same polarizing voltage and low frequency cut off. It is, however, not too easy to take the full advantage of this fact as the cartridge with the low sensitivity will normally have a small internal cavity volume in order to keep the mechanical dimensions as small as possible. The small internal cavity volume requires a high air leak resistance which is very critical to manufacture within narrow tolerances.

B. The Over-All Performance at High Altitudes.

To obtain a picture of the over-all performance of a condenser microphone at high altitudes, the mechanical elements, which determine the sensitivity and especially the frequency characteristic of the microphone, must be considered. Fig. 17 shows a simplified mechanical model of a B & K microphone with the flat front and its electrical analogue circuit valid below and around the principal resonance. In the analogy circuit masses are represented by inductors and compliances by capacitors. It should be noted that Compliance is

$$\frac{1}{\text{stiffness}} = C$$

The masses moved by the sound pressure consist of the diaphragm mass itself together with the air "cushion" on both sides of the diaphragm. In the case of a microphone of the type 4131, the diaphragm mass is 4.4 mg/cm^2 and the mass of the air "cushion" approximately 1.5 mg/cm^2 calculated according to the formula for the movement of air masses in Helmholtz' resonators given by Lord Rayleigh.*

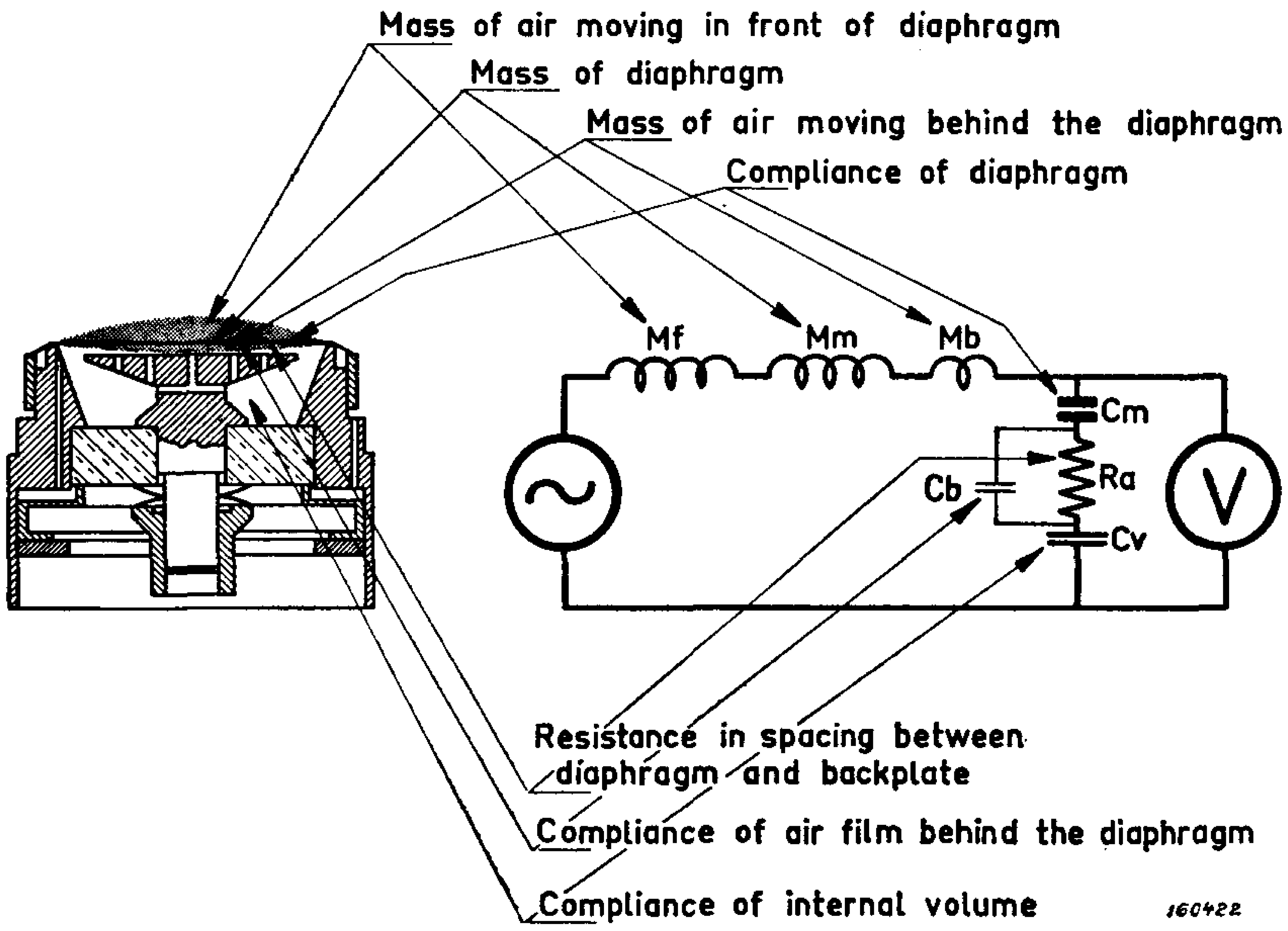


Fig. 17. Equivalent curcuit of the Condenser Microphone (pressure type) around and below the first resonance.

The compliance, which will allow a certain movement of the diaphragm, concists of the compliance of the diaphragm itself and the compliance of the air film between the diaphragm and the back electrode. This film is very thin (small capacity C_b) and will, therefore, be of importance at very high frequencies only. The main air volume of the cartridge will be of greater importance below the resonance frequency of the cartridge. To bring the movement of the diaphragm in contact with this volume, however, the air behind the diaphragm must first pass through a number of small holes in the back electrode. The compliance of the main air volume is relatively large compared with the compliance of the diaphragm (15% of the air volume).

The resistance r consists of the friction in the movement of the air particles between the diaphragm and the back electrode. The resistance is determined by the spacing between the back electrode and the diaphragm, the distance between the holes in the back electrode, and the distance between the holes and the edge. The output voltage of the microphone is proportional to the deflection x of the diaphragm, the deflection being determined by:

* Theory of Sound, Vol. II, Chapter XVI, 2nd Ed. London 1896.

$$x = \frac{F}{\left[r + j\,\omega\,(M_f + M_m + M_b) + \frac{1}{j\,\omega}\left(\frac{1}{C_m} + \frac{1}{C_v}\right)\right] j\,\omega}$$

Where F = applied force on the diaphragm. It can be seen from the expression that to obtain a frequency independent characteristic both the resistance r and the masses must be negligible in comparison to the stiffnes. (stiffness = 1/compliance). This is the case in the frequency range below the resonance frequency. Around the resonance frequency the masses as well as the resistance will influence the characteristic and at exactly the resonance frequency the deflection amplitude, x, is determined by the resistance r only. This explains why it is very important that the holes in the back electrodes must be made with very great accuracy. During the production of Brüel & Kjær microphones, the resistance r is adjusted individually for each microphone cartridge. If the above formula was valid also at frequencies above the resonance frequency, the sensitivity would drop off up to 12 db per octave at high frequencies. In practice, however, the drop will not be the above mentioned 12 db per octave owing to the air volume between the diaphragm and the back electrode (C_b), which together with the increased impedance of the masses constitutes a new resonance above the main resonance. This explains why the distance between the back electrode and the diaphragm as well as the prestressing of the diaphragm must be thoroughly adjusted during production.

After having briefly discussed the elements which are of importance for the movement of the microphone diaphragm, it might be of interest to see what happens when the ambient pressure decreases, i.e. the performance of the microphone at high altitudes.

At frequencies well below the resonance frequency, where both the masses and the resistance are negligible, the air stiffnes $1/C_v$ and $1/C_b$ will decrease because of the decrease in air density, i.e. the capacities in the electrical analogy will be greater. The result will be an increase in sensitivity, which, when the air density is almost vacuum, is determined by the stiffnes of the diaphragm only. Because the over-all stiffness of the system also during operation in normal atmospheric pressure mainly consists of the diaphragm stiffness, the increase in sensitivity at low atmospheric pressure is only of the order of 1 db. Around the resonance frequency the change in performance with air density is more complicated. When the atmospheric pressure decreases the air masses M_f and M_b become smaller because of the reduction in air density. The resistance r, however, will be constant until the air pressure has decreased to such an extent that the mean free path of the molecules is of the same order of magnitude as the distance between the diaphragm and the back electrode.

At medium atmospheric pressures a displacement of the resonance towards higher frequencies is to be expected, see Figs. 19 and 20. Because the masses are decreased, but the resistance r keeps its value constant, the change in damping, if any, should consist of a slight increase.

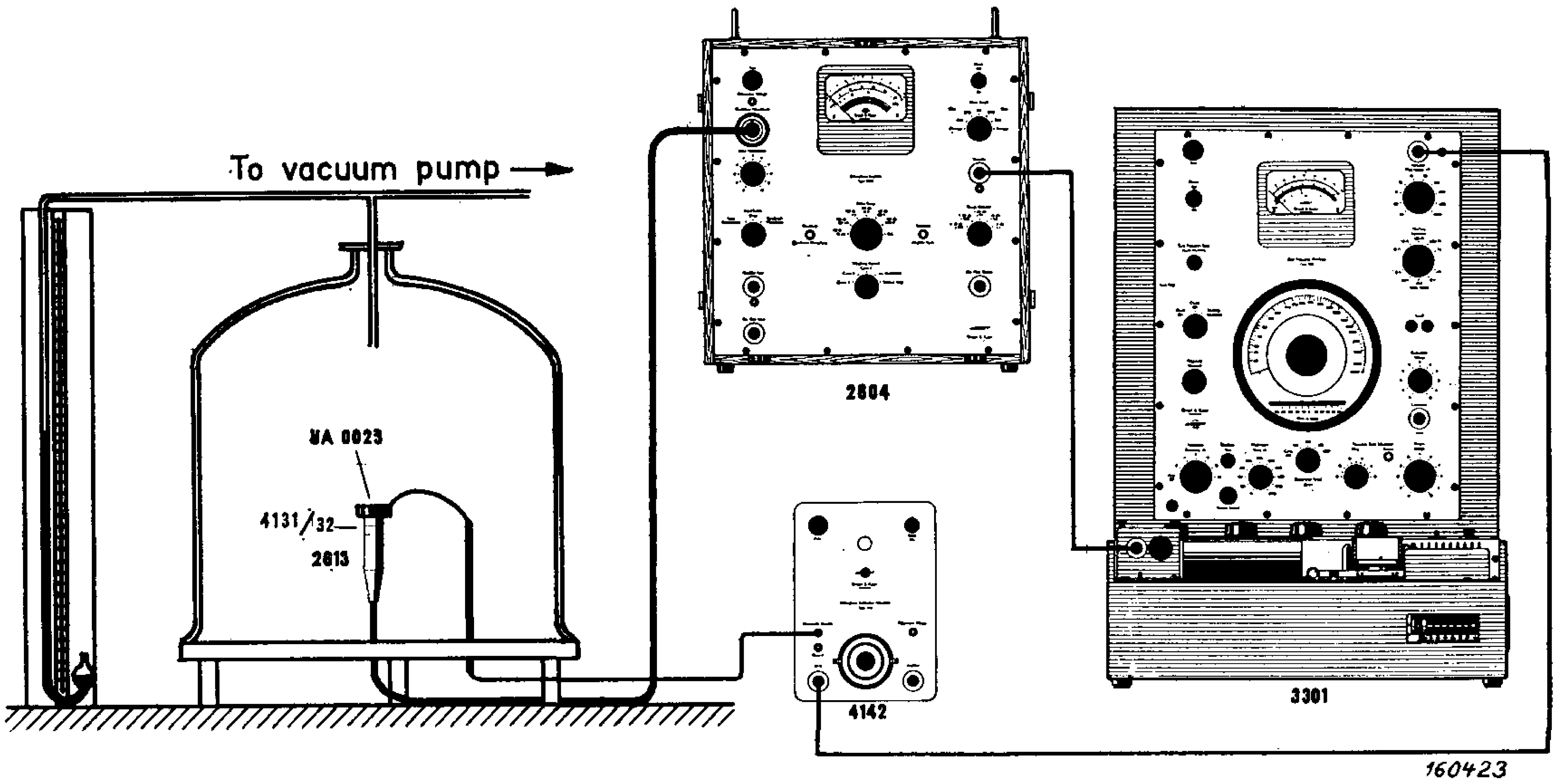


Fig. 18. Measuring arrangement used to determine the frequency characteristic of the microphones as a function of the ambient static pressure.

If the atmospheric pressure is decreased even more an air pressure will be reached where the resistance r starts to decrease. This happens when the magnitude of the mean free path of the air molecules is approaching the distance between the diaphragm and the back electrode. The damping will then decrease rapidly with further decrease in air pressure and the frequency characteristic of the microphone will show a very pronounced resonance peak.

At the same time the influence of the main volume C_v, will become greater with respect to C_b because of the decrease in resistance r, see Fig. 17. The resonance of the system moves therefore at very low air pressures towards lower frequencies, Figs. 19 and 20.

The variation in over-all operation of a condenser microphone with increasing altitude can therefore be summarized as follows:

1. The sensitivity at frequencies well below the resonance will increase slightly with altitude.
2. The damping of the resonance will remain unchanged until a certain value of the ambient air pressure is reached, whereafter it will decrease rapidly with decreasing pressure.

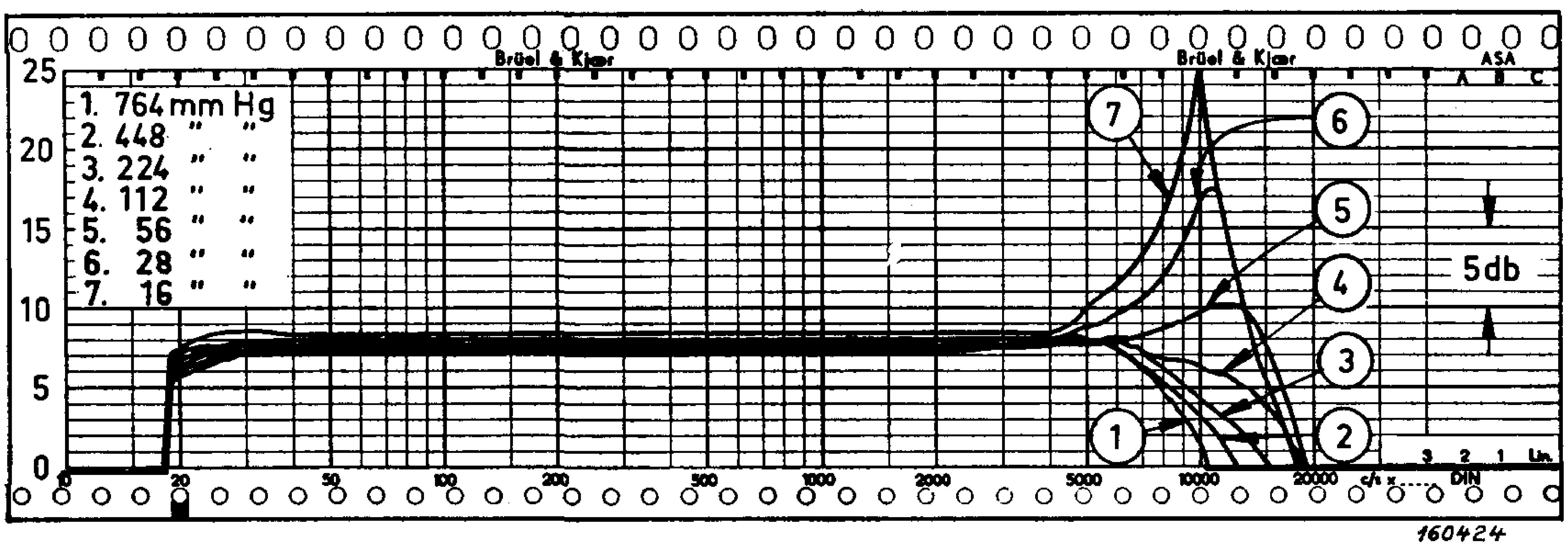
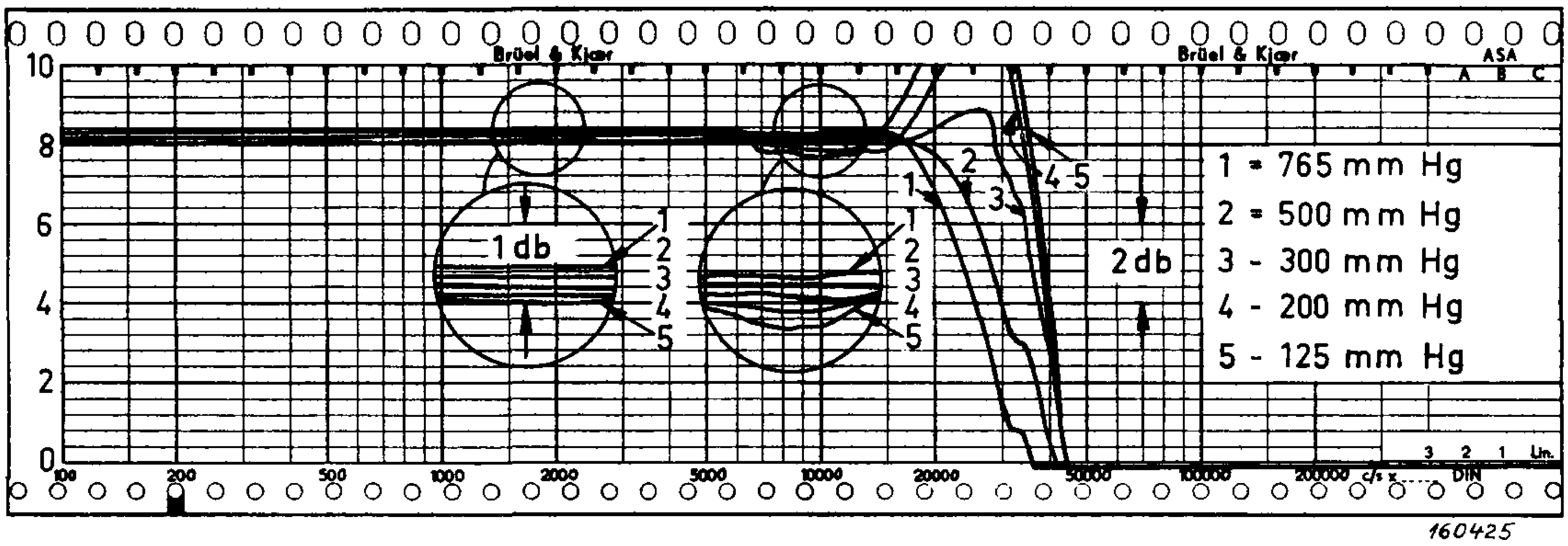


Fig. 19. Pressure response characteristics for 24 mm Type 4132 cartridges at varying ambient pressures.

3. The resonance will in the beginning move towards higher frequencies as long as the damping remains constant. At lower air pressures, however, it will move towards lower frequencies.



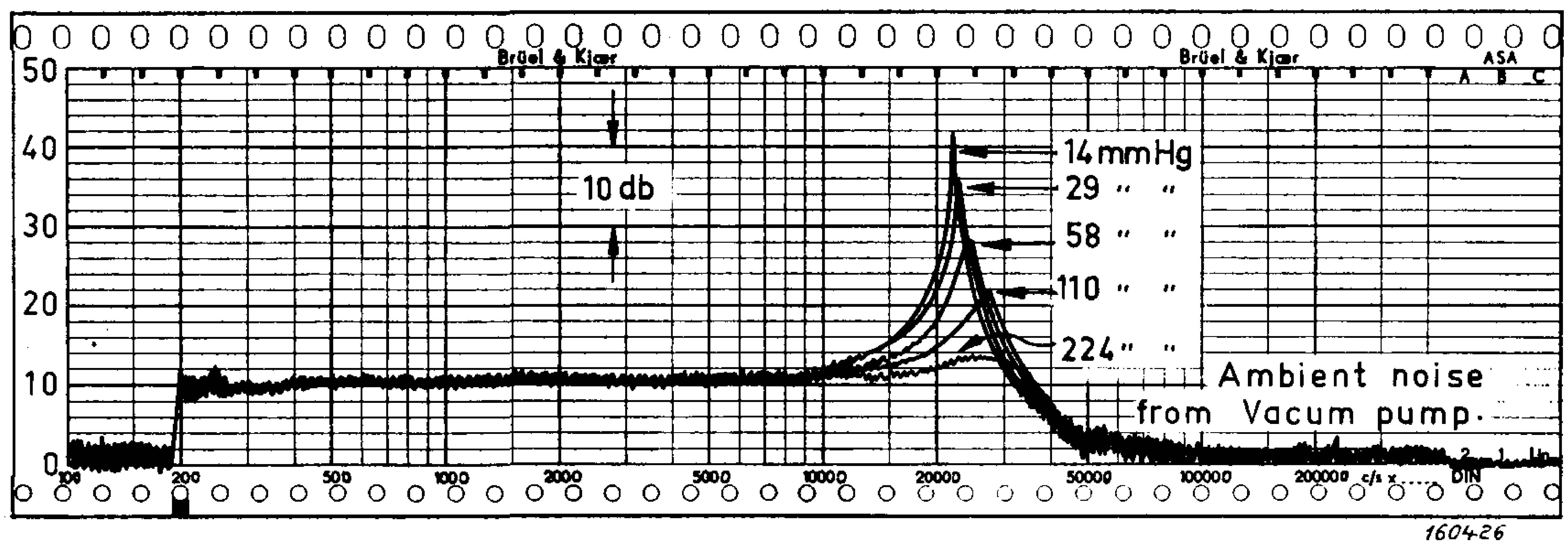


Fig. 20. a) Pressure response characteristics for ½" michrophone Type 4134 at different ambient pressure 765—125 mmHg.

b) Pressure response characteristics for ½" microphone Type 4134 at different ambient pressures 224—14 mmHg.

The above considerations are valid for condenser microphones with a sufficiently low diaphragm mass, for example B & K Cartridges Type 4131/32 and 4133/34. (For most other condenser microphones the diaphragm mass is 2—5 greater). The change in frequency characteristic and sensitivity of the B & K microphones has been measured at different air pressures under constant temperature conditions. The measurements were made by means of an electrostatic actuator as shown in Fig. 18.

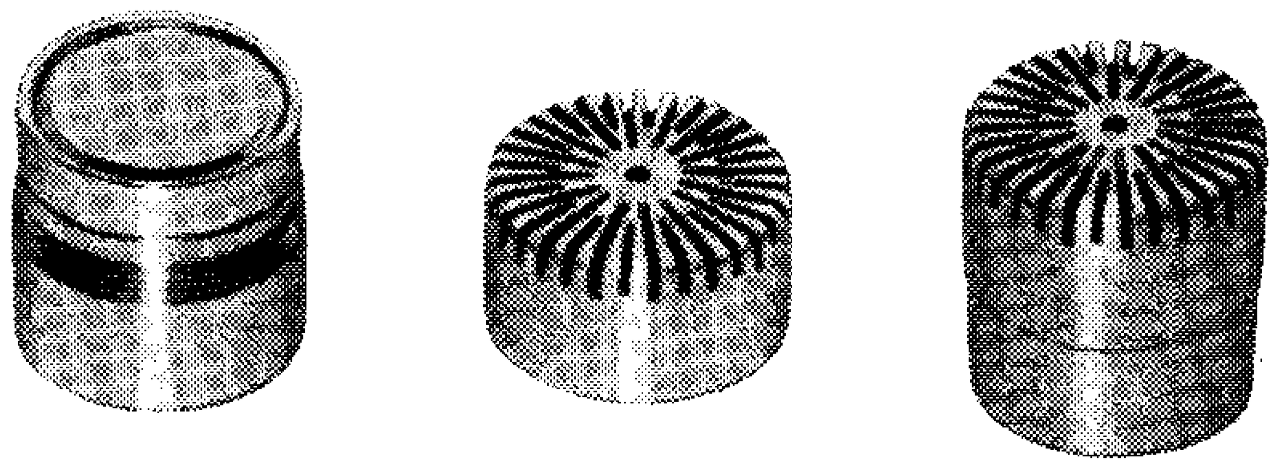
The microphone cartridge with cathode follower and actuator was placed in a glass container where the air pressure could be lowered and accurately measured on a connected manometer. In Figs. 19 and 20 the measured results are shown. The air pressure is given in mmHg.

From the curves it can be seen that the frequency characteristic of the cartridge Type 4132 remains flat to within 2 db up to 4.5 kc/s, and in case of the cartridge Type 4134 up to 10 kc/s, under all the specified measuring conditions.

News from the Factory.

New Microphone Equipment.

Two new Microphone Cartridges have been developed together with associated Cathode Followers and Calibration Equipment.



Microphone Cartridges Type 4133/34.

Microphone Cartridge Type 4133.

This cartridge has an outside diameter of ½ inch and an open circuit sensitivity of approx. 1.5 mV/μbar (—57 db re. 1 V/μbar). The free field response for 0° sound incidence is linear to within ± 2 db from 20 c/s. — 40000 c/s.

When used with one of the Cathode Followers Type 2614 or 2615 the dynamic range is 32 db to 160 db re 2×10^{-4} μbar (weighted) for less than 4% distortion, and the temperature coefficient is approx. 0,01 db/°C at 20° C (within 0,5 db from —30° C to 160° C).

Each microphone is individually calibrated.

The mechanical construction is similar to the normal 24 mm B & K Condenser Microphones.

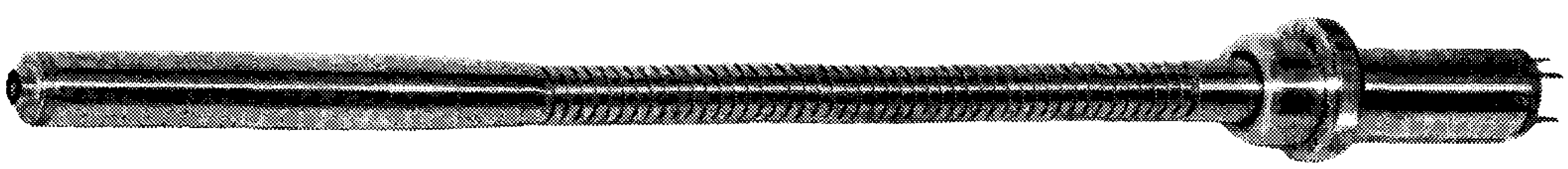
Microphone Cartridge Type 4134.

Similar to Type 4133 except for the frequency range which is flat for random incidence and pressure response to within 2 db from 20 c/s. — 20000 c/s.

The equivalent volume is approx. 0,012 cm^3. Each microphone is individually calibrated.

Cathode Followers Type 2614 and 2615.

The two models are electrically identical units. The mechanical construction, however, is different in that the Cathode Follower Type 2614 is mounted on a flexible gooseneck, while Type 2615 is supplied with a 2 m length of cable.

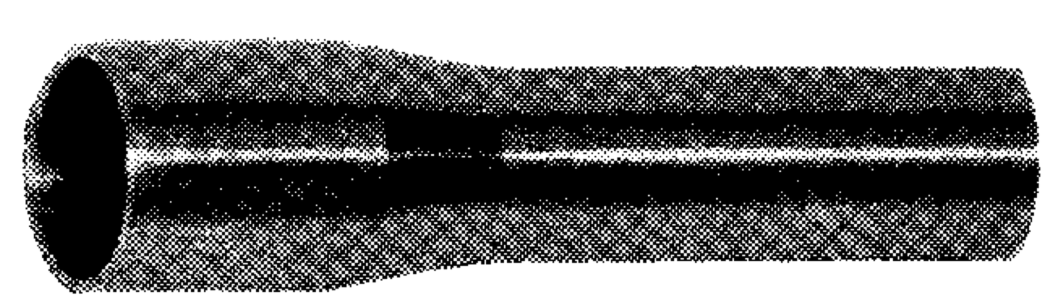


Cathode Follower Type 2614.

The outside diameter of the cathode followers is the same as that of the microphone cartridges (½″), and the length of the cylindrical housing is approximately 7 cm (2¾″).

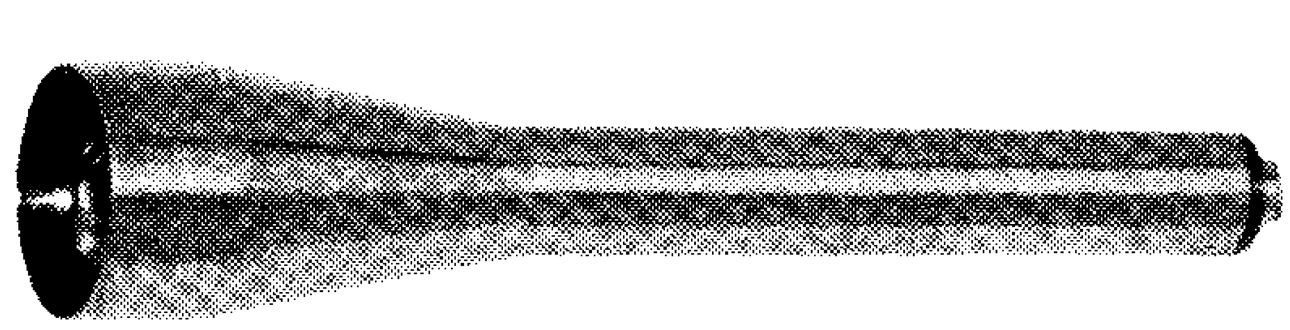
Cathode Follower Type 2615.

Both cathode followers are provided with connectors for direct connection to either of the B & K microphone amplifiers or frequency analysers from which they derive the necessary power supplies.
They are supplied from the factory together with the Adaptor JJ 2614, which replaces the Microphone Cartridge when it is desired to use the cathode followers as high input impedance "amplifiers" (for example in connection with the B & K Accelerometers).
The input impedance is approx. 700 MΩ and the output impedance 750 Ω. Transmission loss approx. 0,8 db.



Adaptor JJ 2614.

Adaptor UA 0030.
This unit enables the ½" Microphone Cartridges Type 4133 and 4134 to be used together with the 24 mm Cathode Followers Type 2612 and 2613.



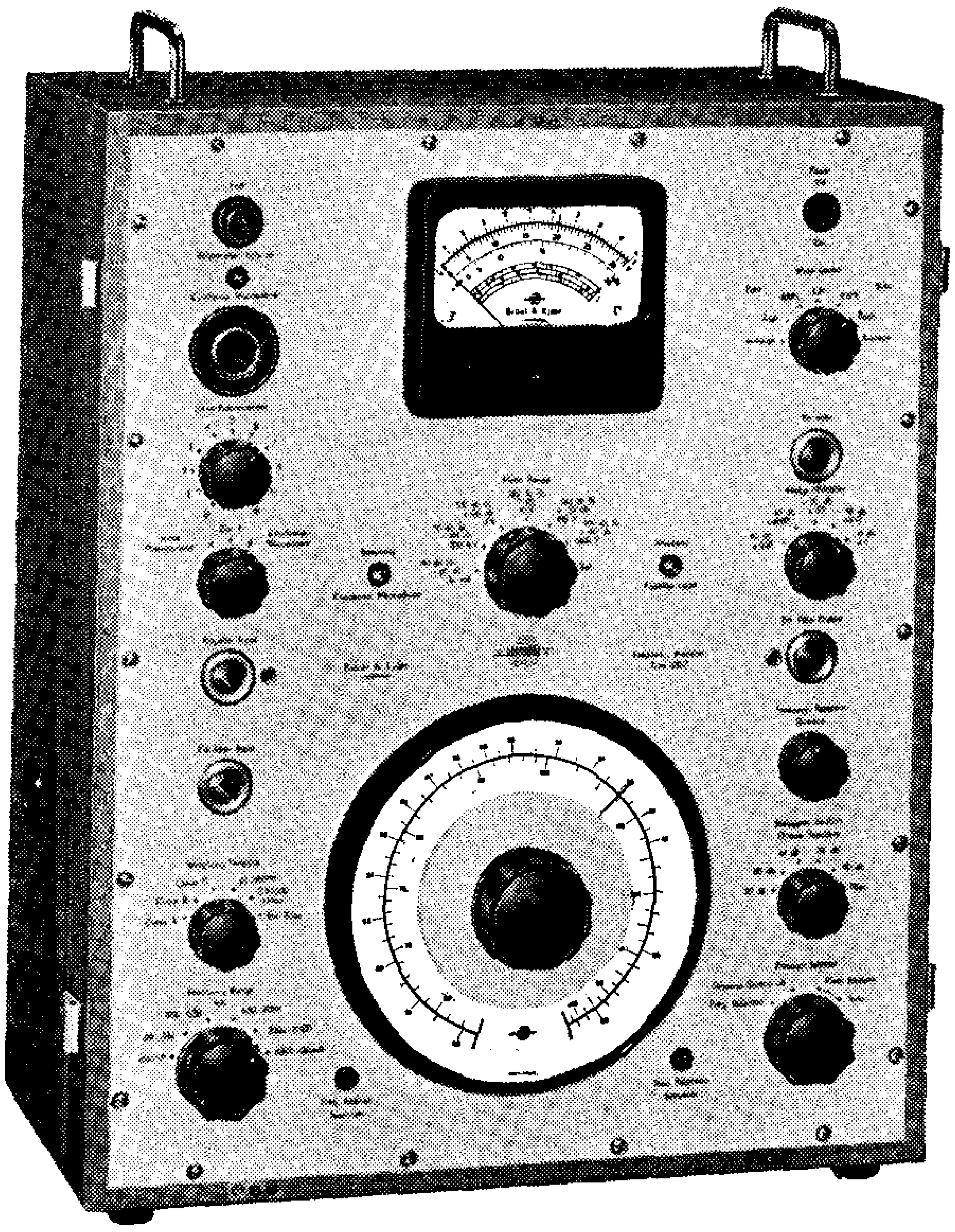
Adaptor UA 0030.

Electrostatic Actuator U A 0033.

Electrostatic Actuator UA 0033
for pressure response measurements on the ½″ Microphone Cartridges Type 4133 and 4134.

Microphone Calibration Apparatus Type 4142.
The Microphone Calibration Apparatus Type 4141 for reciprocity calibration of the B & K Condenser Microphones has been modified so that it now also enables the calibration of the ½″ Microphone Cartridges Type 4133 and 4134. The modified Calibration Apparatus has the Type No. 4142.

New Frequency Analyzer Type 2107.
Type 2107 is an AC operated audio frequency analyzer of the constant percentage bandwidth type. It has been designed especially as a narrow band sound and vibration analyzer, but may be used for any kind of frequency analysis and distortion measurement with the frequency range 20 c/s. — 20000 c/s. A built-in mechanical device enables automatic tuning from an external motor, e. g. the motor in one of the B & K Level Recorders. When used together with a B & K Level Recorder frequency amplitude diagrams can be recorded automatically.
The analyzer can also be used as a linear amplifier and a vacuum tube voltmeter in the frequency range 2 c/s. — 35000 c/s. It contains, furthermore, the internationally standardized weighting networks for sound level measurements and a 7-poled input socket for connection of a B & K Condenser Microphone or Preamplifier.
The instrument is supplied with the special B & K, R.M.S.-Average and Peak rectifier and meter circuits and facilities are provided for connection of external



Frequency Analyzer Type 2107.

filters, for example the ⅓ octave Filter Set Type 1610, between the amplifier stages.

Sensitivity: Full scale deflection from 100 μV to 1000 V in 10 db steps on two attenuators, Maximum amplification 100 db.

Input Impedance: 2,22 MΩ parallelled by 30 $\mu\mu$F.

Output Impedance: Smaller than 50 Ω.

Maximum available output is approx. 45 volts peak.

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